Conceptual Framework for Studying the Effects of Reduced Nitrogen Inputs to the Delta

SFEI: David Senn, Amy Richey, April Robinson
USGS: Tamara Kraus, Anke Mueller-Solger

SFEI | AQUATIC SCIENCE CENTER
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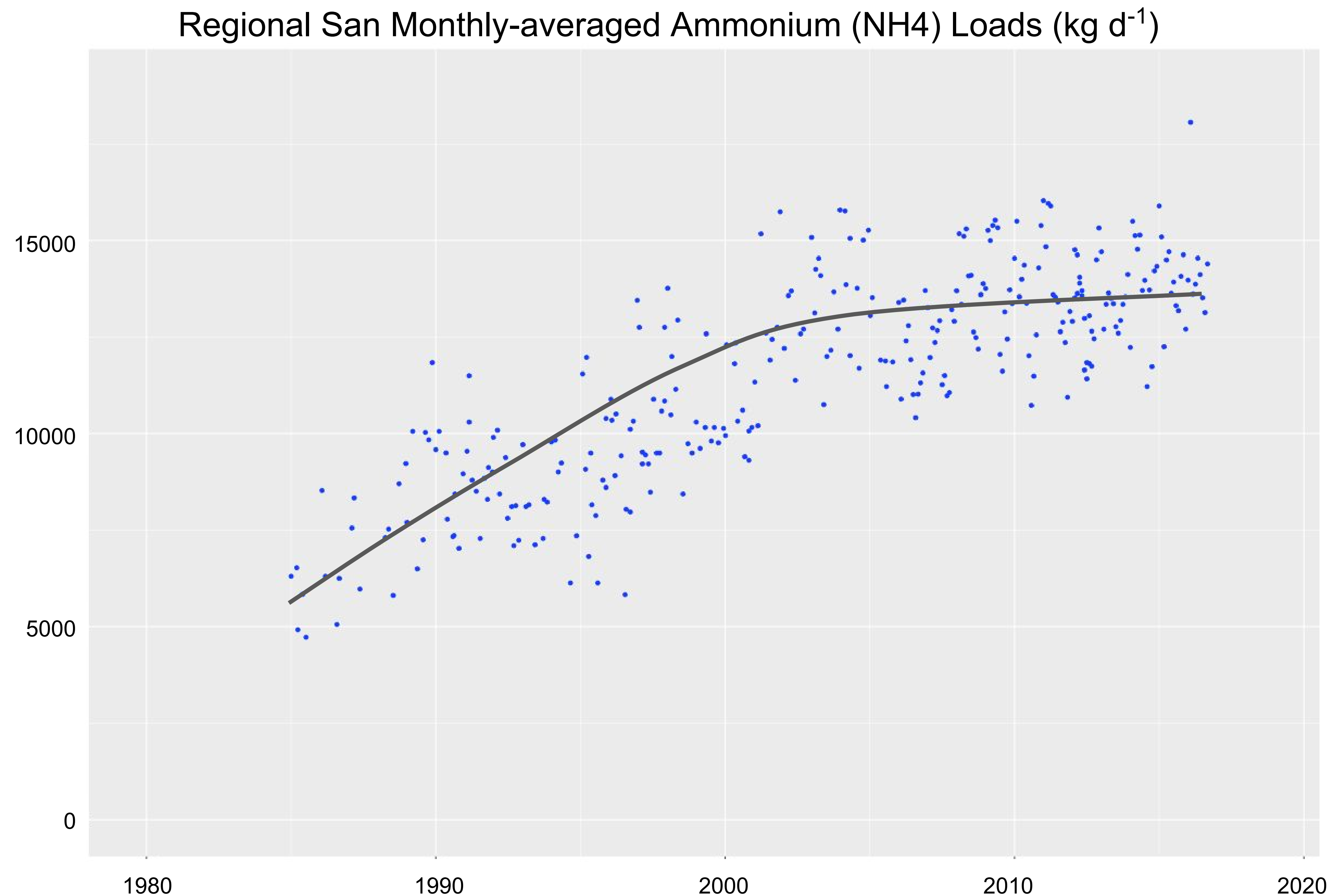
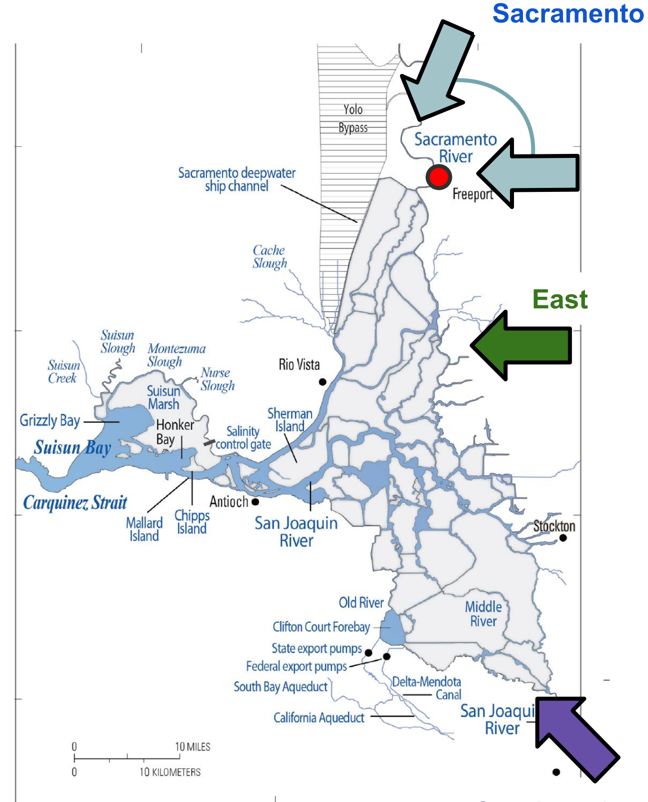


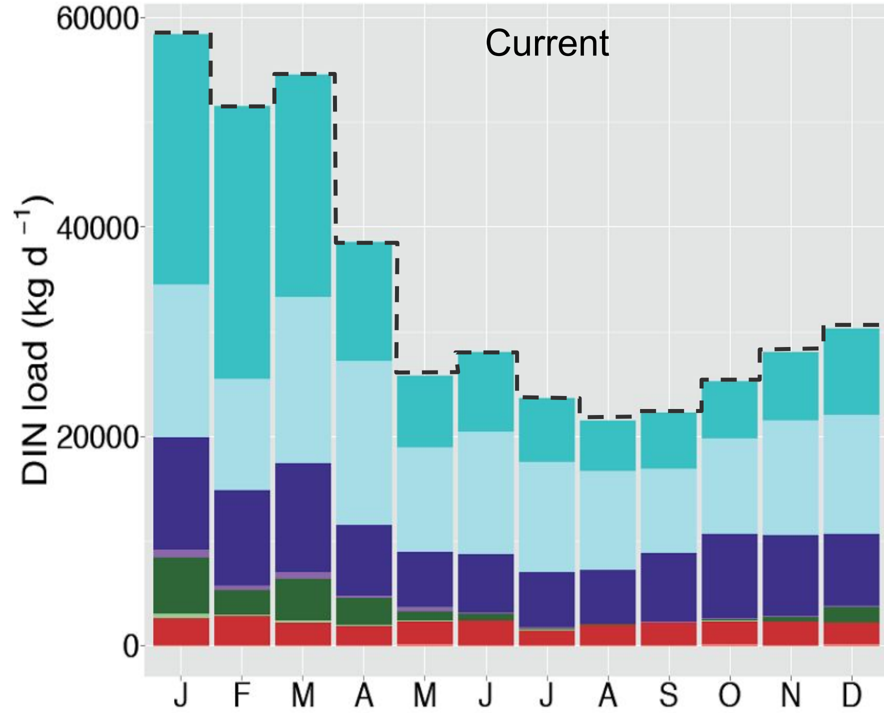
Figure A.X: (likely to go in appendix) Regional San NH4 loads vs. time.Data: Jassby 2008, LWA 2017, Regional San pers. communication

Nutrient Loads to the Delta



Regional San WWTP discharge location

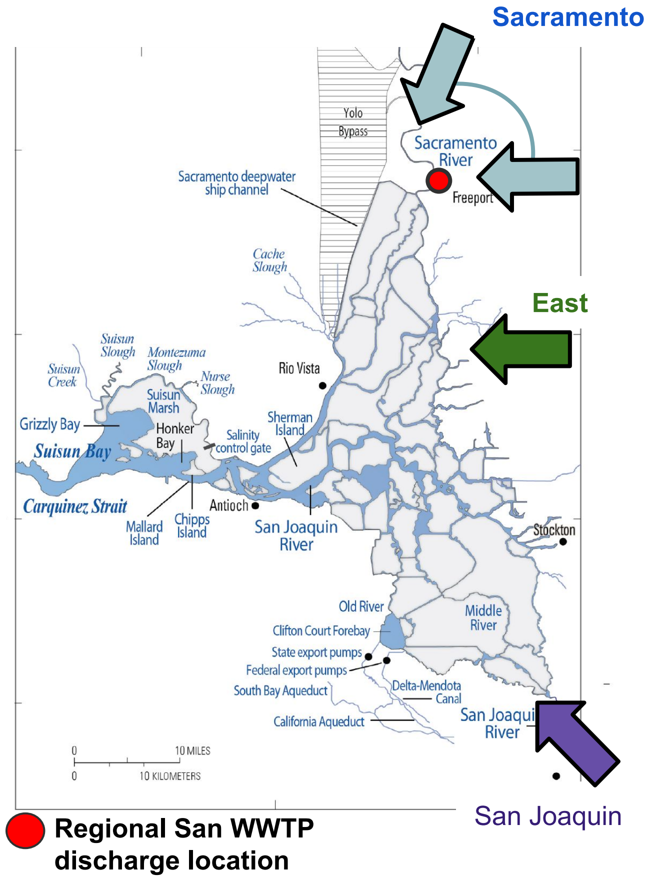
Current
Regional San load, NH4
~14000 kg N/d

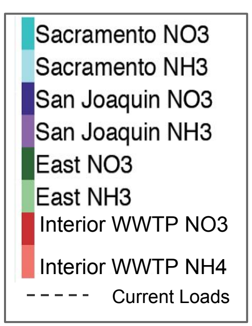


Sacramento NO3
Sacramento NH3
San Joaquin NO3
San Joaquin NH3
East NO3
East NH3
Interior WWTP NO3
Interior WWTP NH4
Current Loads

SFEI 2014; SFEI 2015

Nutrient Loads to the Delta





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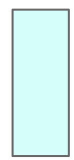
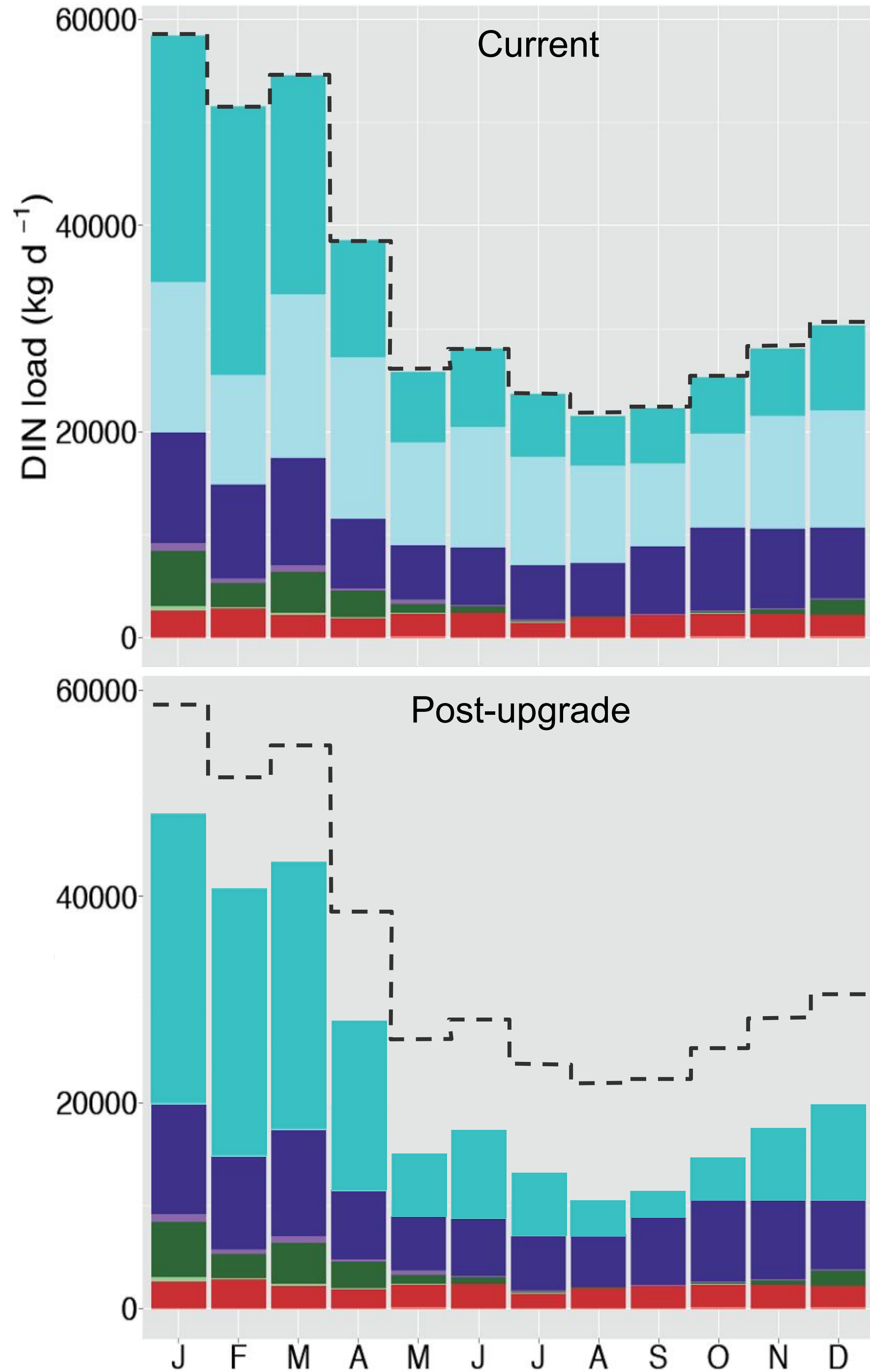
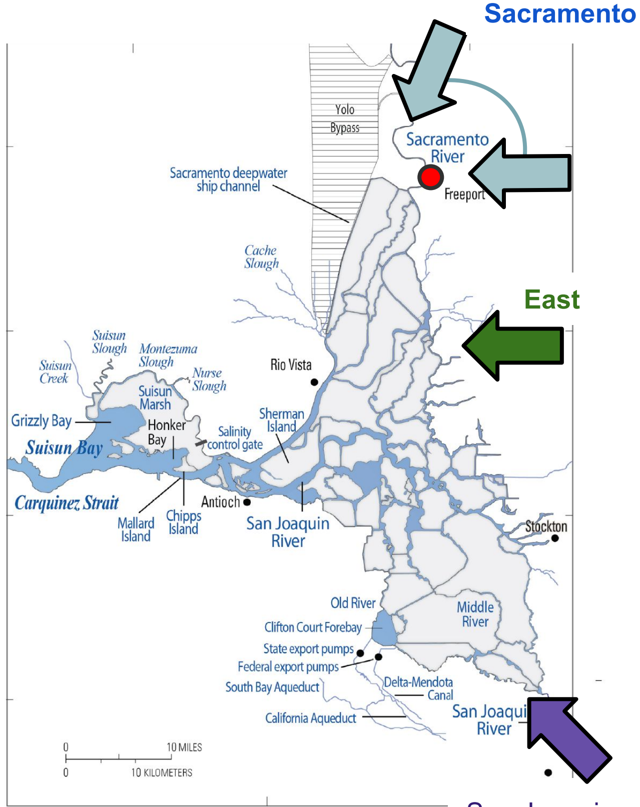


Future
Regional San load, N03
~3500 kg N/d



SFEI 2014; SFEI 2015

Nutrient Loads to the Delta



Regional San WWTP discharge location

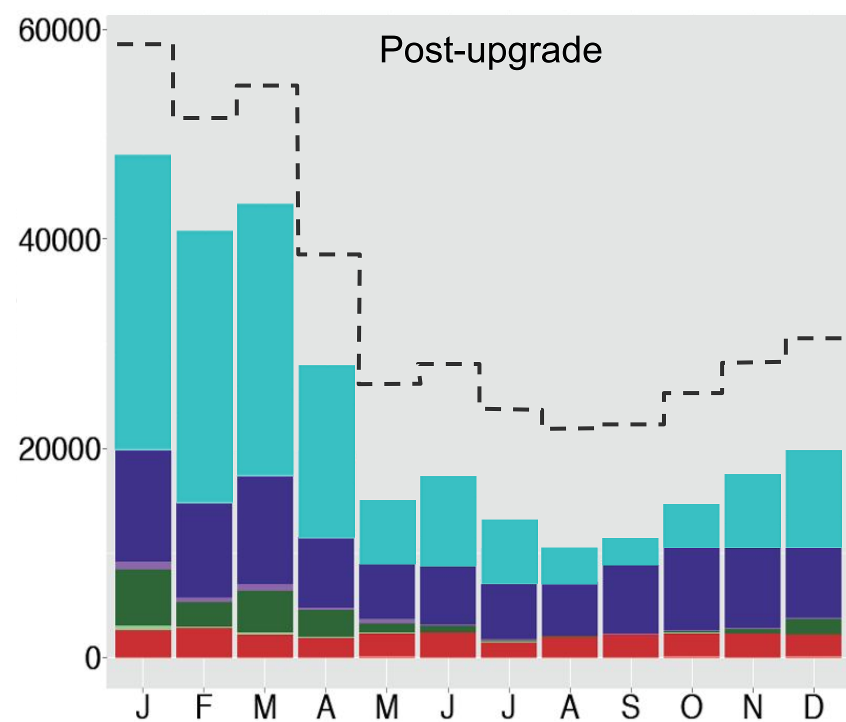
How will Delta and nSFE habitats respond to this abrupt and seemingly large change?

What intensive investigations and longer-term monitoring are needed to characterize and quantify the effects?

What baseline data are needed to capture pre-upgrade conditions?

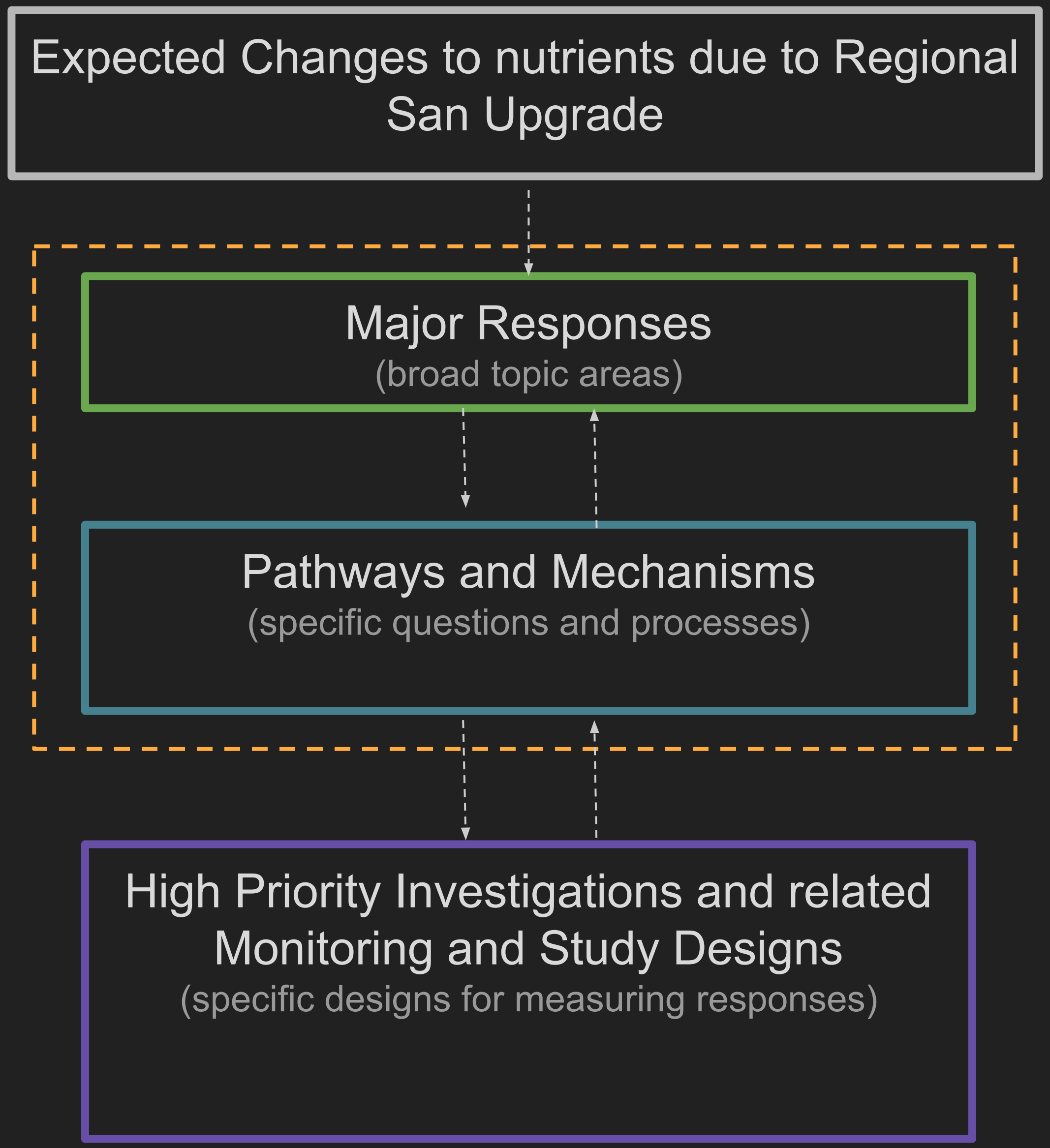
- Sacramento NO3
- Sacramento NH3
- San Joaquin NO3
- San Joaquin NH3
- East NO3
- East NH3
- Interior WWTP NO3
- Interior WWTP NH4
- Current Loads

Future
Regional San load, N03
~3500 kg N/d

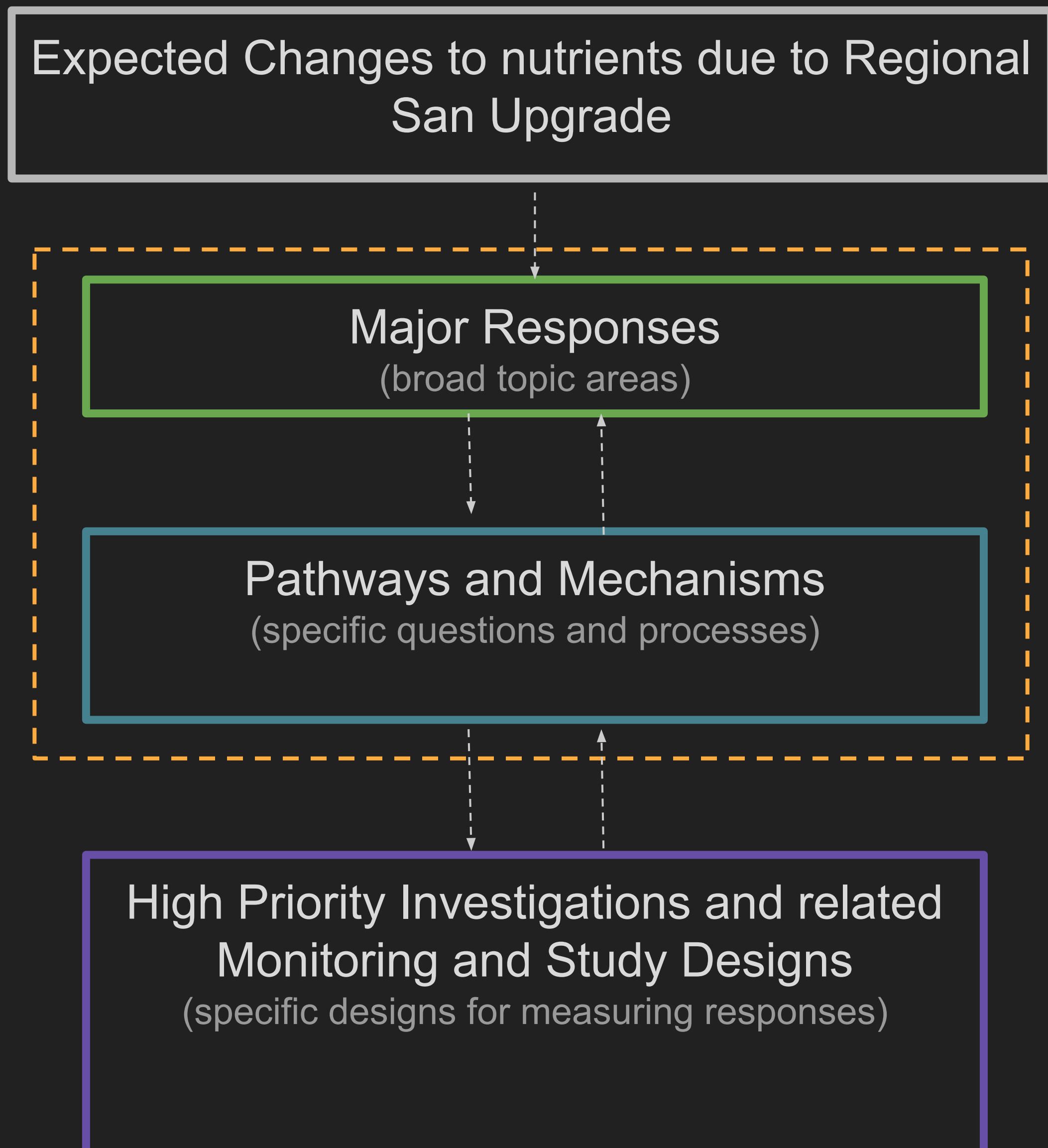


SFEI 2014; SFEI 2015

Overall Project Goals



Overall Project Goals



1. ***Nutrient load changes***
2. ***Identify priority high-level "Responses"***
3. ***Plausible** changes, **Feasible** to detect*
   - ***[nutrients]***
   - ***responses***
4. ***Prioritize and Design Studies***
   What, Where, when?

Fall 2018

Studies launched!
Well-vetted, high-priority studies, collecting critical baseline data

Feb '18

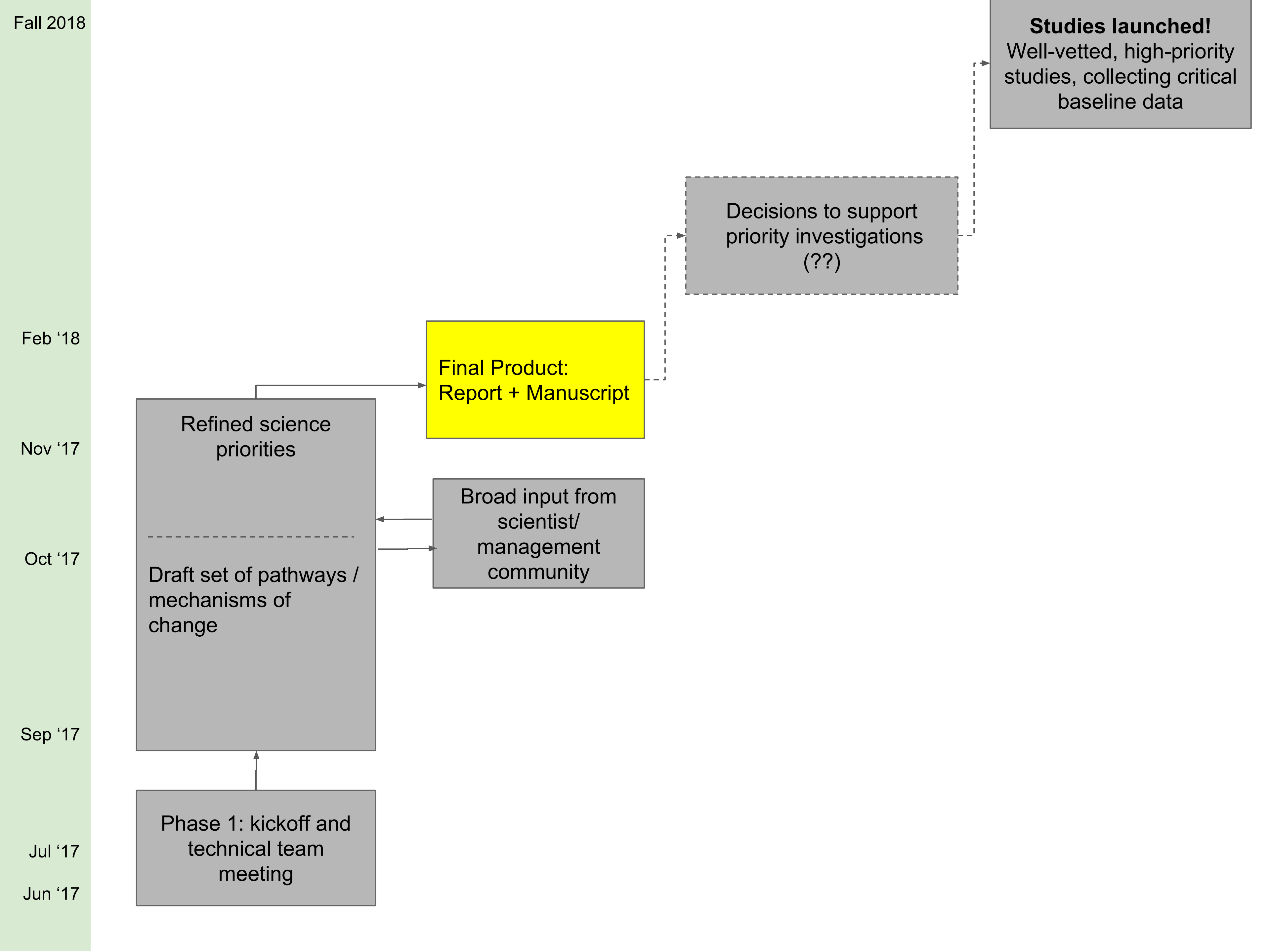
Nov '17

Oct '17

Sep '17

Jul '17

Jun '17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Decisions to support priority investigations (??)
Final Product: Report + Manuscript
Refined science priorities
Draft set of pathways / mechanisms of change
Broad input from scientist/ management community
Phase 1: kickoff and technical team meeting

Project Team

	Louise Conrad	DWR	Fish, aquatic vegetation
	Larry Brown	USGS	Food webs
	Carol Kendall	USGS	Isotope geochemistry
	Tim Otten	Bend Genetics	Harmful algae
	Chris Francis	Stanford	N cycling, microbes
	Jan Thompson	USGS	Benthic ecology
	Wim Kimmerer	SFSU-RTC	Zoop ecology
	Alex Parker	CSUM	Phytoplankton ecology
	Raphe Kudela	UCSC	Phytoplankton ecology
	Brian Bergamaschi	USGS	Biogeochemistry
*	Dave Senn	SFEI	Biogeochemistry
*	Tamara Kraus	USGS	Biogeochemistry
*	Anke Mueller-Solger	USGS	Phyto/Zoop ecology
*	Amy Richey	SFEI	Ecology
*	April Robinson	SFEI	Wetland ecology
*	Dylan Stern	DSP	Environmental science/policy

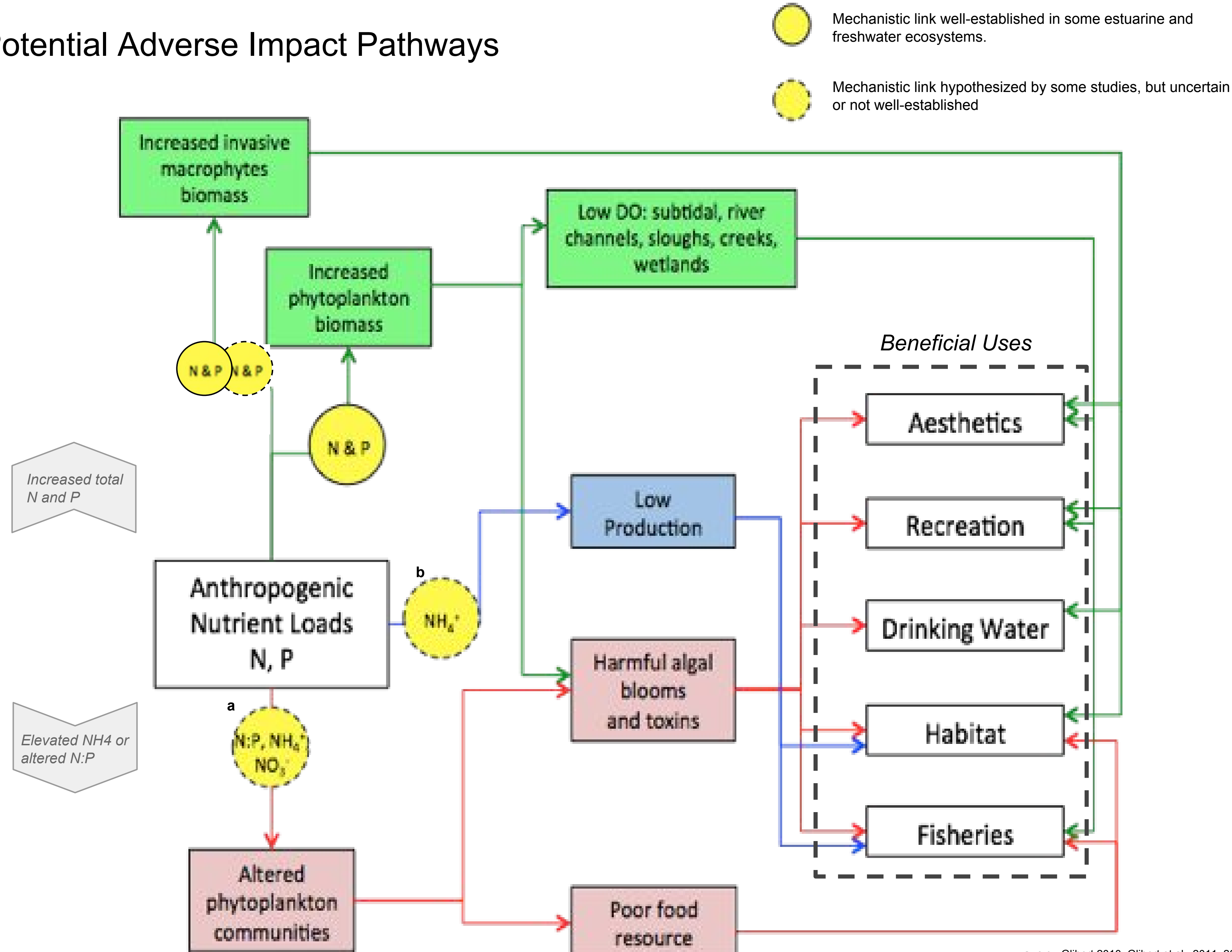
Meetings:

July 13 2017

August 3 2017

November 2017

Potential Adverse Impact Pathways



SFEI 2014

a: e.g., Glibert 2010; Glibert et al., 2011, 2016

b: e.g., Dugdale et al 2007; Dugdale et al., 2016

What ‘types of change’ might be expect?

Level 3

Foodweb
Zooplankton, clams, invertebrates, fish, people

Drinking Water Quality
Taste, odor, toxicity

Wetland Restoration

What ‘types of change’ might be expect?

Level 1

Nutrients Themselves
Source Loads, Conc, Form, Ratio

NH4, NO3, DIN
DON, PN, TN

Including: In-Transit Nutrient Sources, Sinks, Transformations

Level 3

Foodweb
Zooplankton, clams, invertebrates, fish, people

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Taste, odor, toxicity

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What ‘types of change’ might be expect?

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Nutrients Themselves
Source Loads, Conc, Form, Ratio

NH4, NO3, DIN
DON, PN, TN

Including:
In-Transit Nutrient
Sources, Sinks, Transformations

Level 2

Primary Production

Phytoplankton

HABs

Aquatic Macrophytes
FAV, SAV, EAV

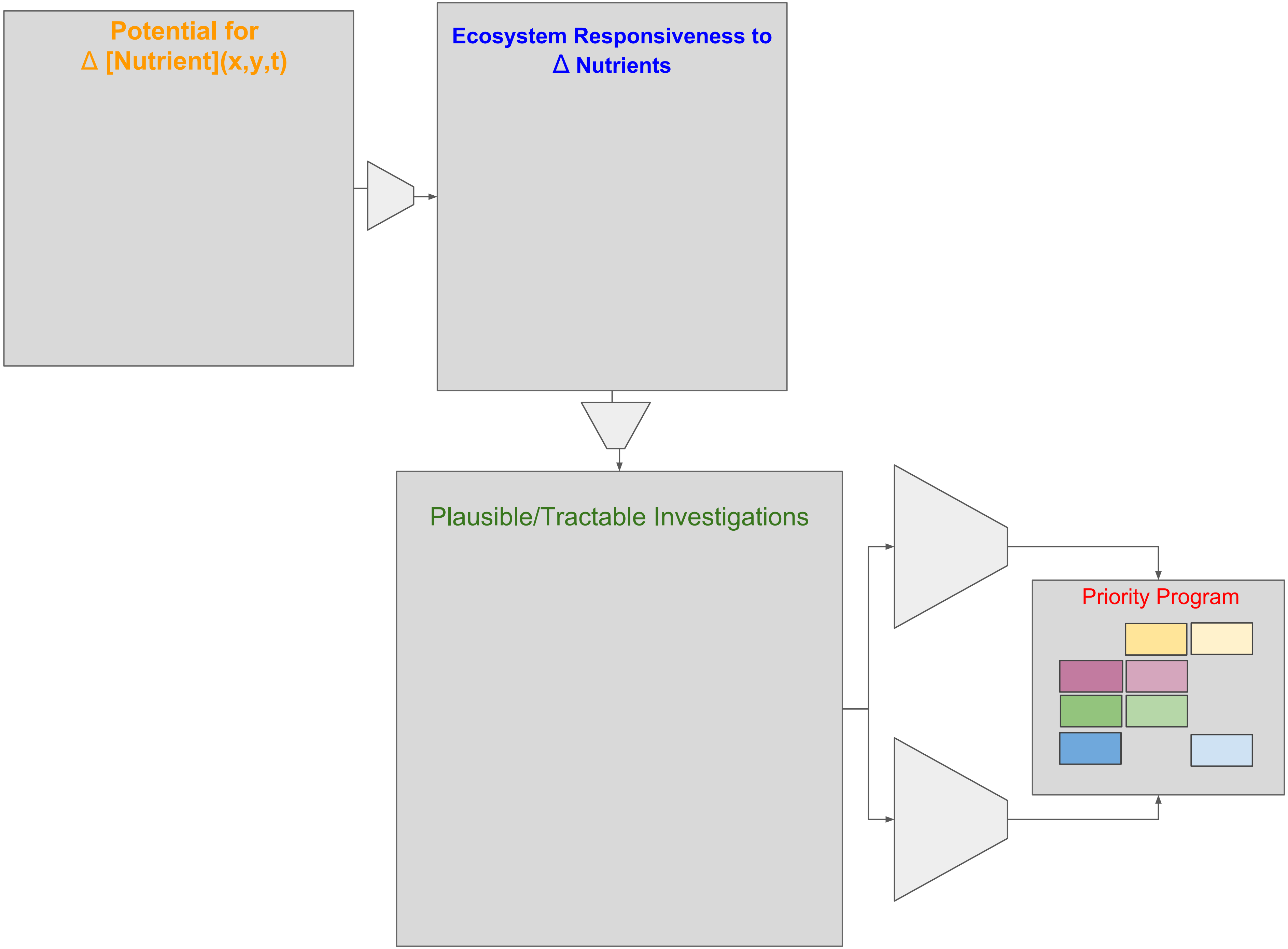
Microbes

Level 3

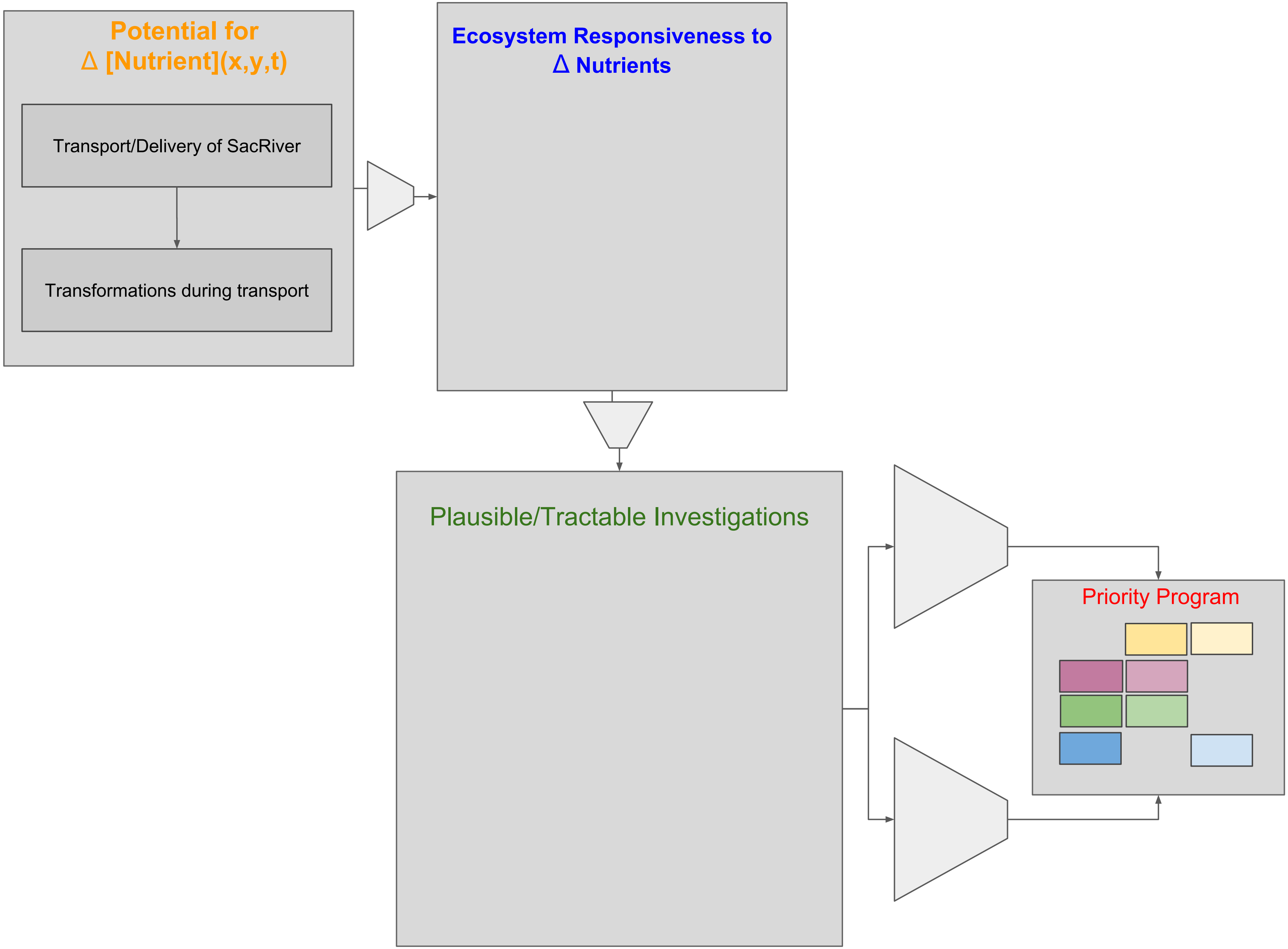
Foodweb
Zooplankton, clams, invertebrates, fish, people

Drinking Water Quality
Taste, odor, toxicity

Wetland Restoration



Potential for
Δ [Nutrient](x,y,t)
Ecosystem Responsiveness to
Δ Nutrients
Plausible/Tractable Investigations
Priority Program


Potential for
Δ [Nutrient](x,y,t)
Transport/Delivery of SacRiver
Transformations during transport
Ecosystem Responsiveness to
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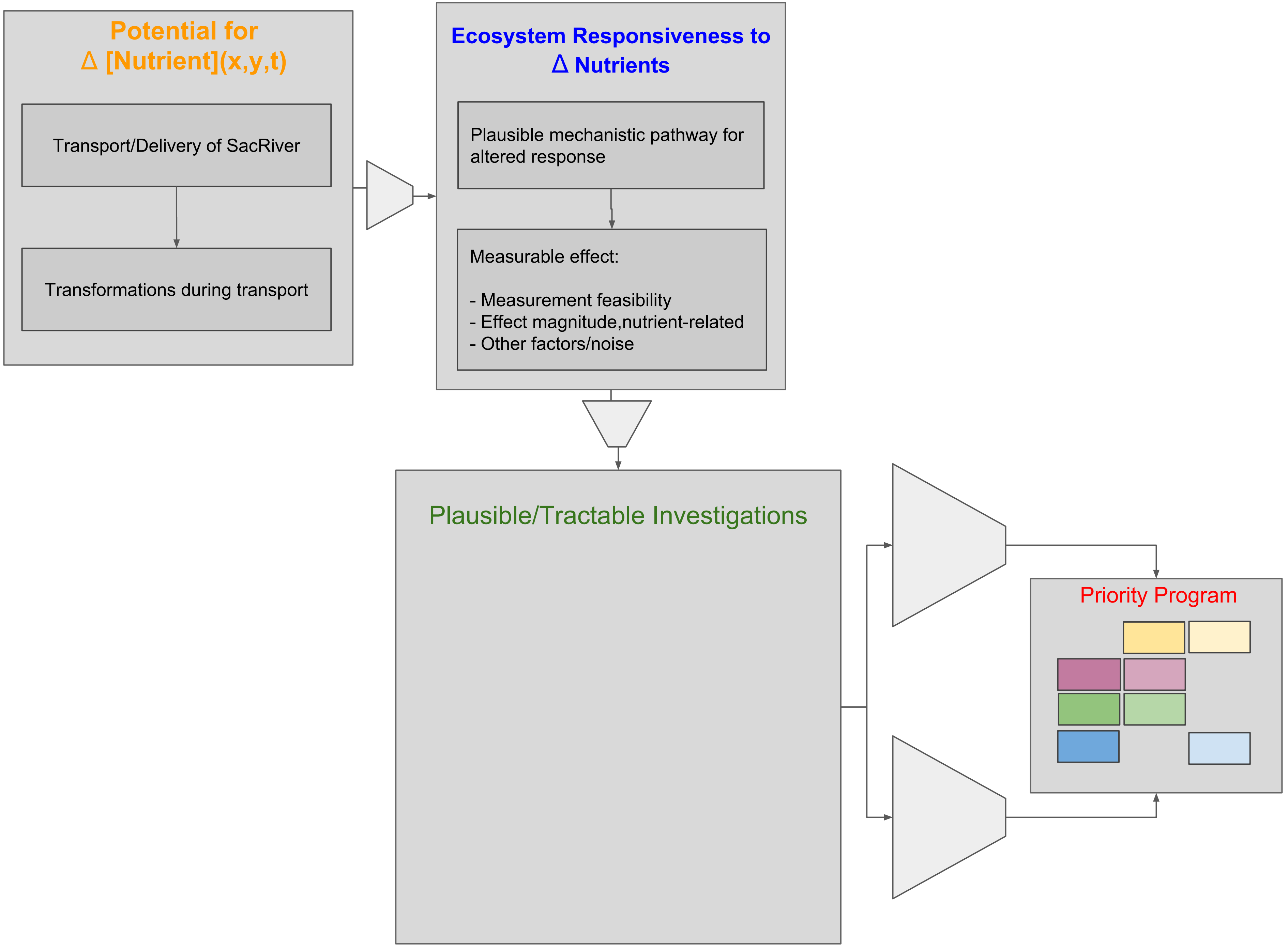
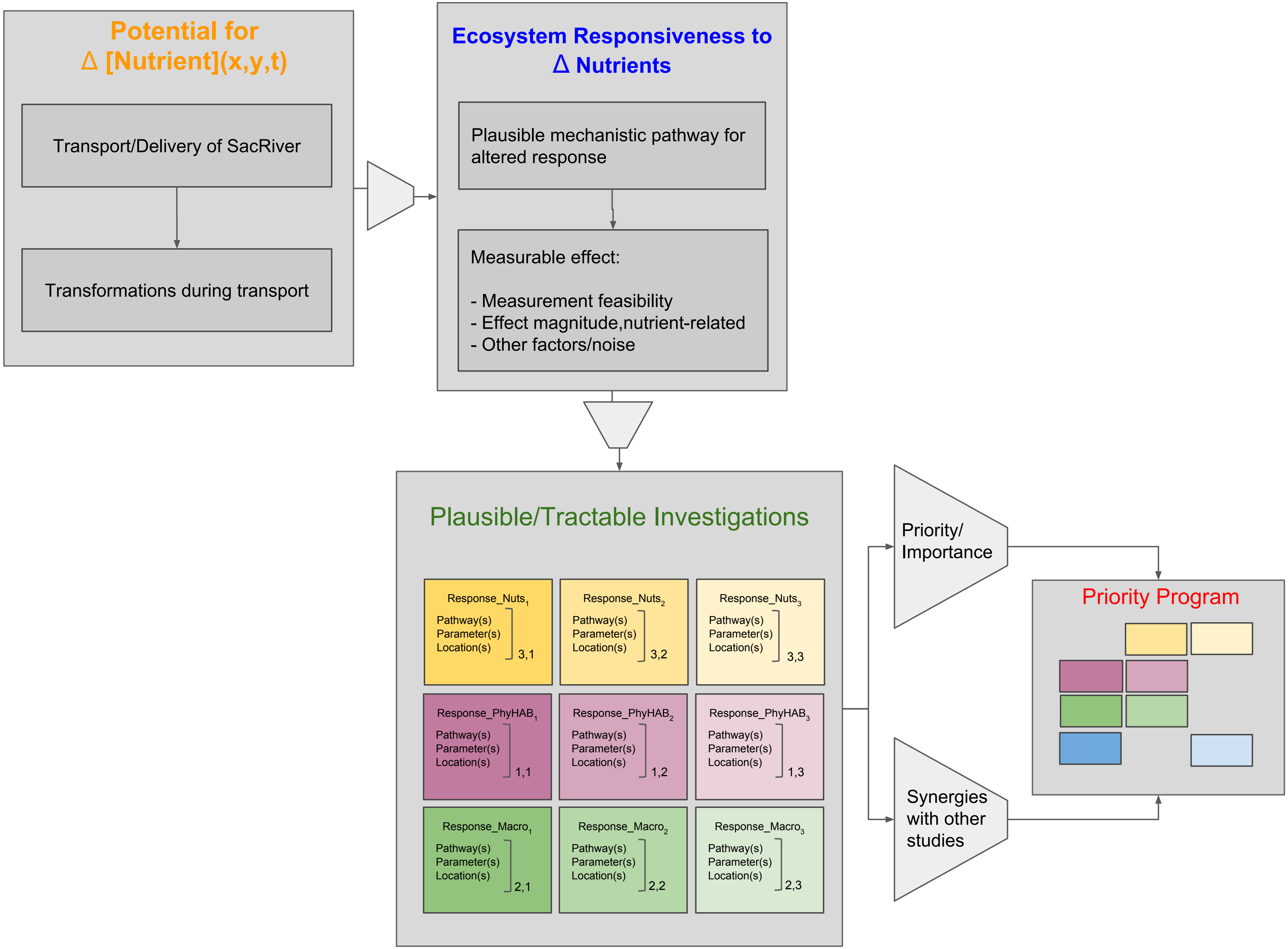


Potential for
Δ [Nutrient](x,y,t)
Transport/Delivery of SacRiver
Transformations during transport
Ecosystem Responsiveness to
Δ Nutrients
Plausible mechanistic pathway for altered response
Measurable effect:
- Measurement feasibility
- Effect magnitude,nutrient-related
- Other factors/noise
Plausible/Tractable Investigations
Priority Program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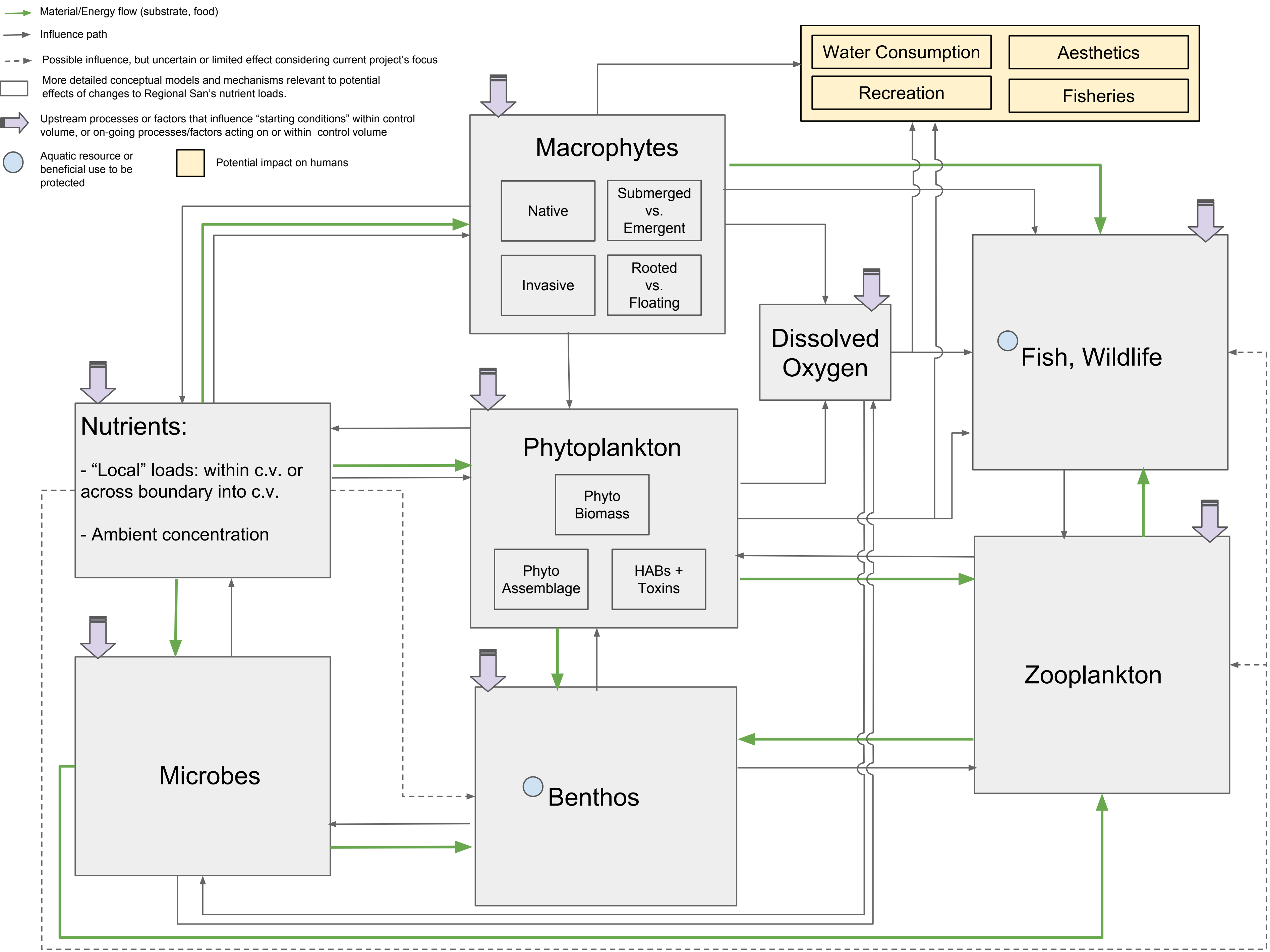
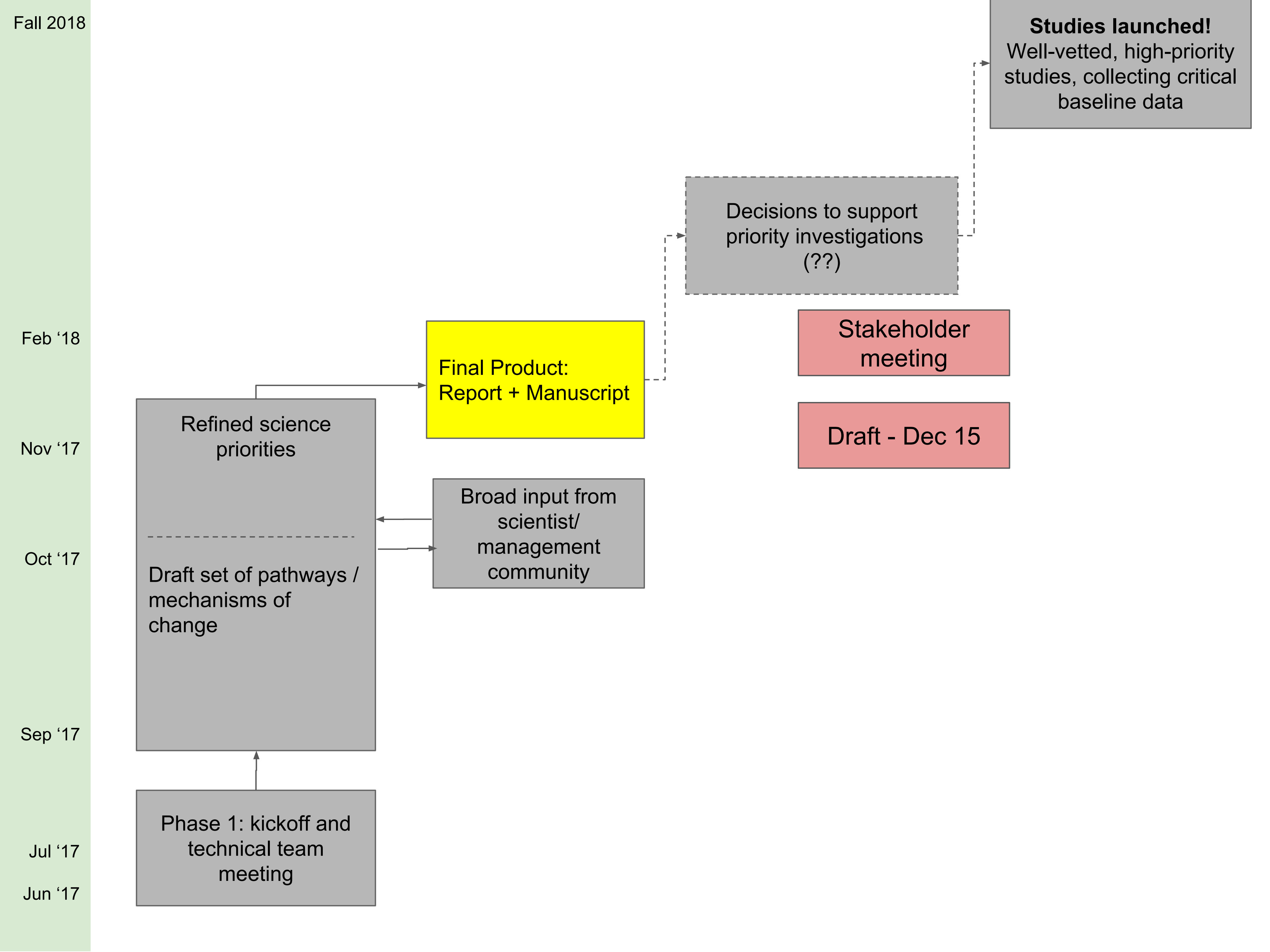
Plausible/Tractable Investigations
Response_Nuts1
Pathway(s)
Parameter(s)
Location(s)
3,1
Response_Nuts2
Pathway(s)
Parameter(s)
Location(s)
3,2
Response_Nuts3
Pathway(s)
Parameter(s)
Location(s)
3,3
Response_PhyHAB1
Pathway(s)
Parameter(s)
Location(s)
1,1
Response_PhyHAB2
Pathway(s)
Parameter(s)
Location(s)
1,2
Response_PhyHAB3
Pathway(s)
Parameter(s)
Location(s)
1,3
Response_Macro1
Pathway(s)
Parameter(s)
Location(s)
2,1
Response_Macro2
Pathway(s)
Parameter(s)
Location(s)
2,2
Response_Macro3
Pathway(s)
Parameter(s)
Location(s)
2,3
Priority/
Importance
Synergies
with other
studies
Priority Program



Material/Energy flow (substrate, food)
Influence path
Possible influence, but uncertain or limited effect considering current project's focus
More detailed conceptual models and mechanisms relevant to potential effects of changes to Regional San's nutrient loads.
Upstream processes or factors that influence "starting conditions" within control volume, or on-going processes/factors acting on or within control volume
Aquatic resource or beneficial use to be protected
Potential impact on humans
Water Consumption
Aesthetics
Recreation
Fisheries
Macrophytes
Native
Submerged vs. Emergent
Invasive
Rooted vs. Floating
Dissolved Oxygen
Fish, Wildlife
Nutrients:
- "Local" loads: within c.v. or across boundary into c.v.
- Ambient concentration
Phytoplankton
Phyto Biomass
Phyto Assemblage
HABs + Toxins
Zooplankton
Microbes
Benthos



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Studies launched! Well-vetted, high-priority studies, collecting critical baseline data
Decisions to support priority investigations (??)
Stakeholder meeting
Draft - Dec 15
Final Product: Report + Manuscript
Refined science priorities
Draft set of pathways / mechanisms of change
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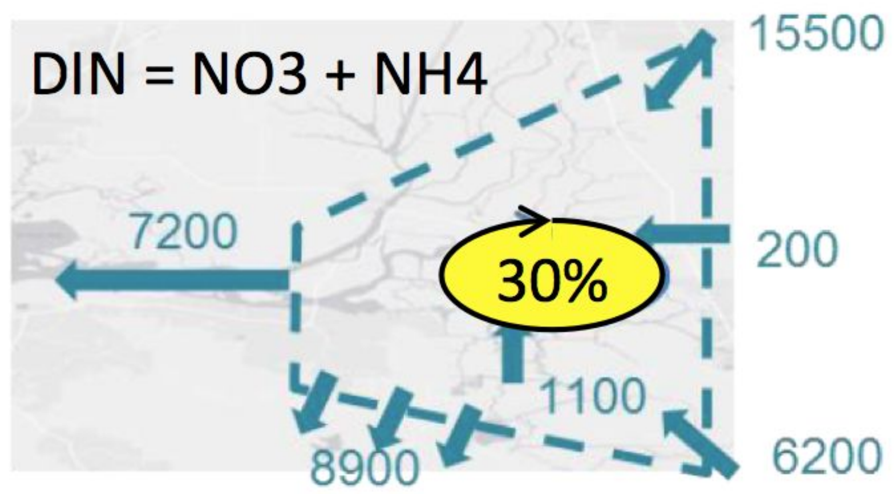
Which areas of the Delta would potentially be most influenced by load changes from Regional San?

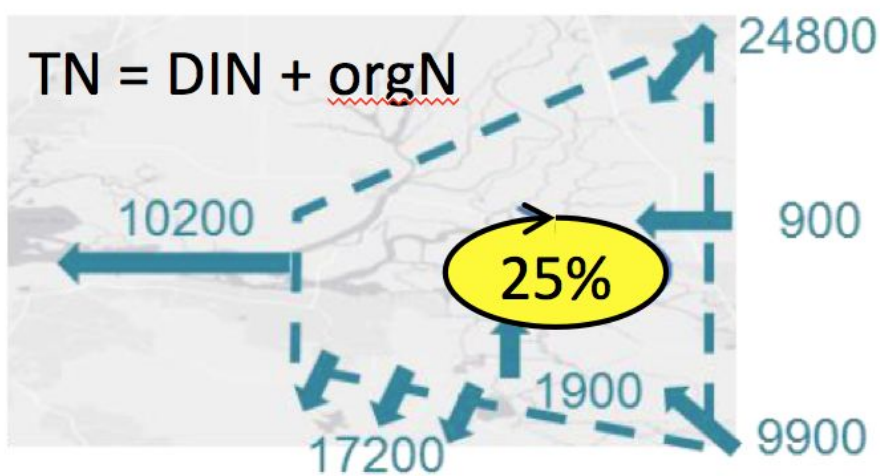
will depend on multiple factors, including…

1. Contribution of Sacramento River water to the ‘mix’ at a given site.
    - f(x,y,t):
        - t ← seasonal cycles, interannual variability

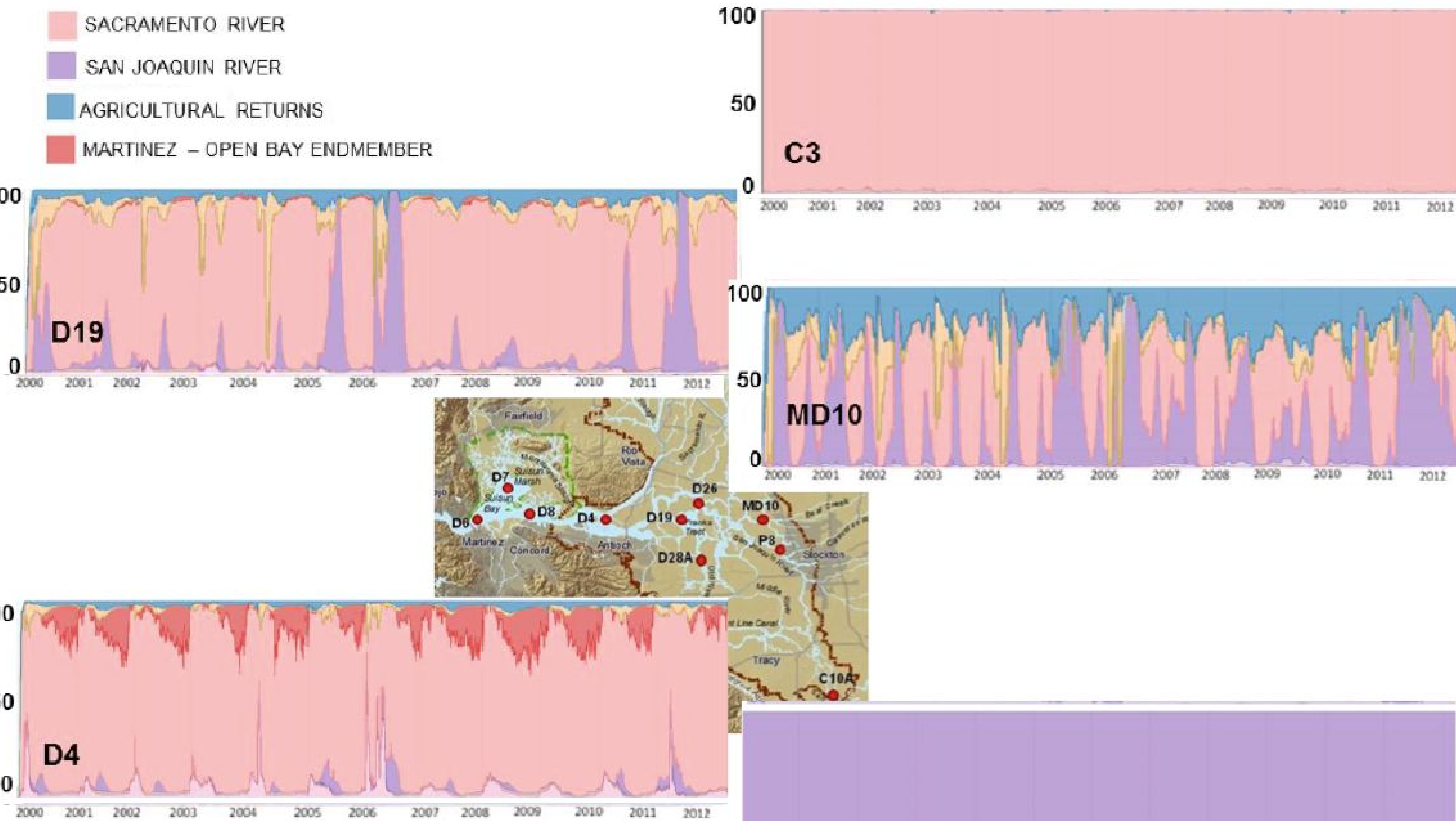
2. The magnitudes of biogeochemical processes/transformations that occur along the flow path Regional San → (x,y)
    - f(x,y,t)
        - t ← seasonal cycles, interannual variability

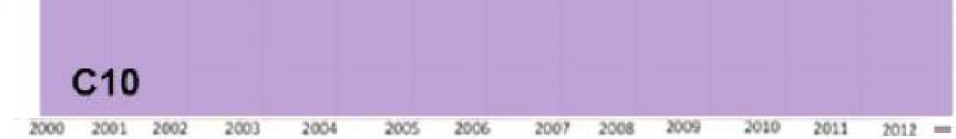
Summer Whole-Delta Mass Balances





SFEI 2015 (Novick et al. 2015)





DSM2 – "Volumetric Fingerprint"

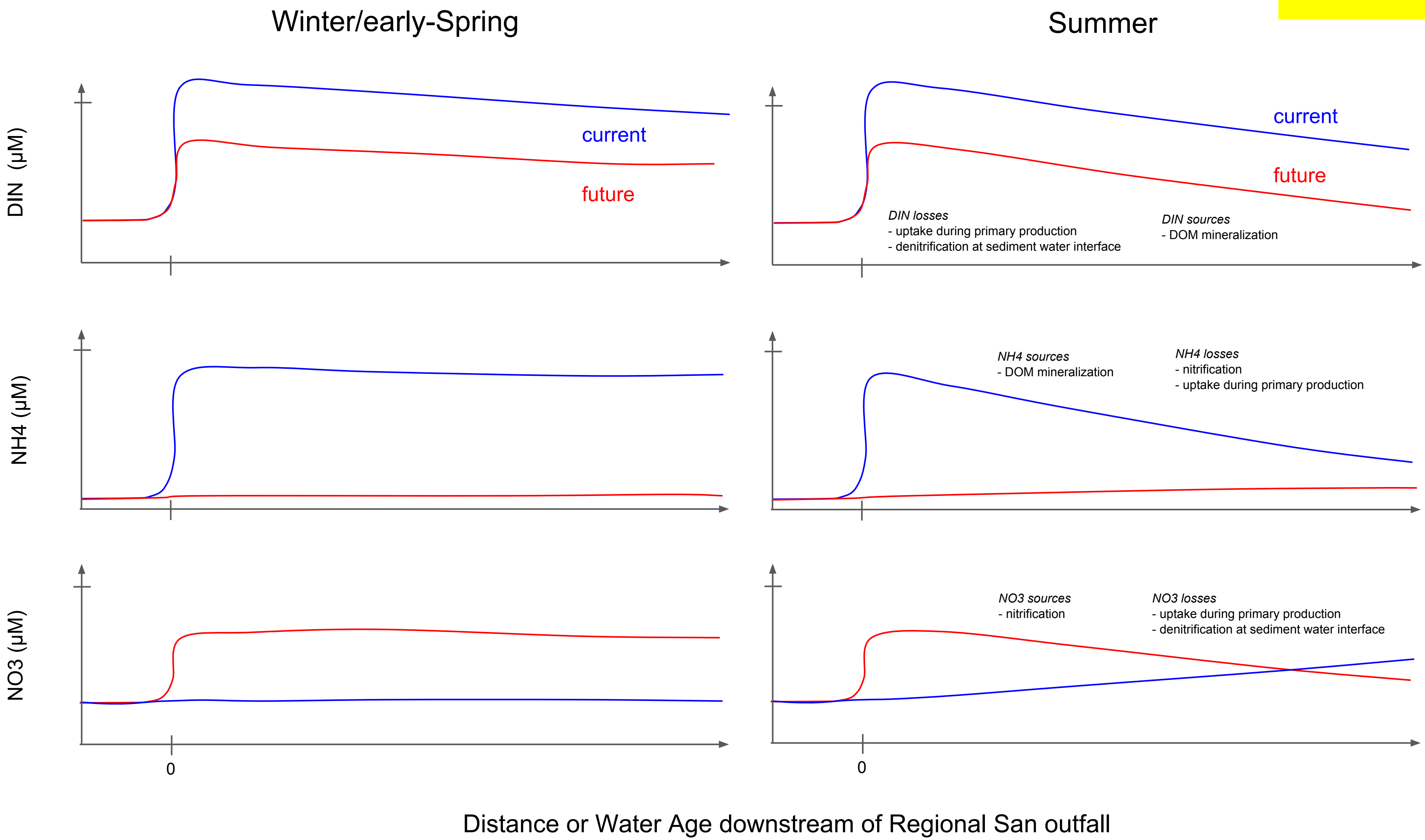
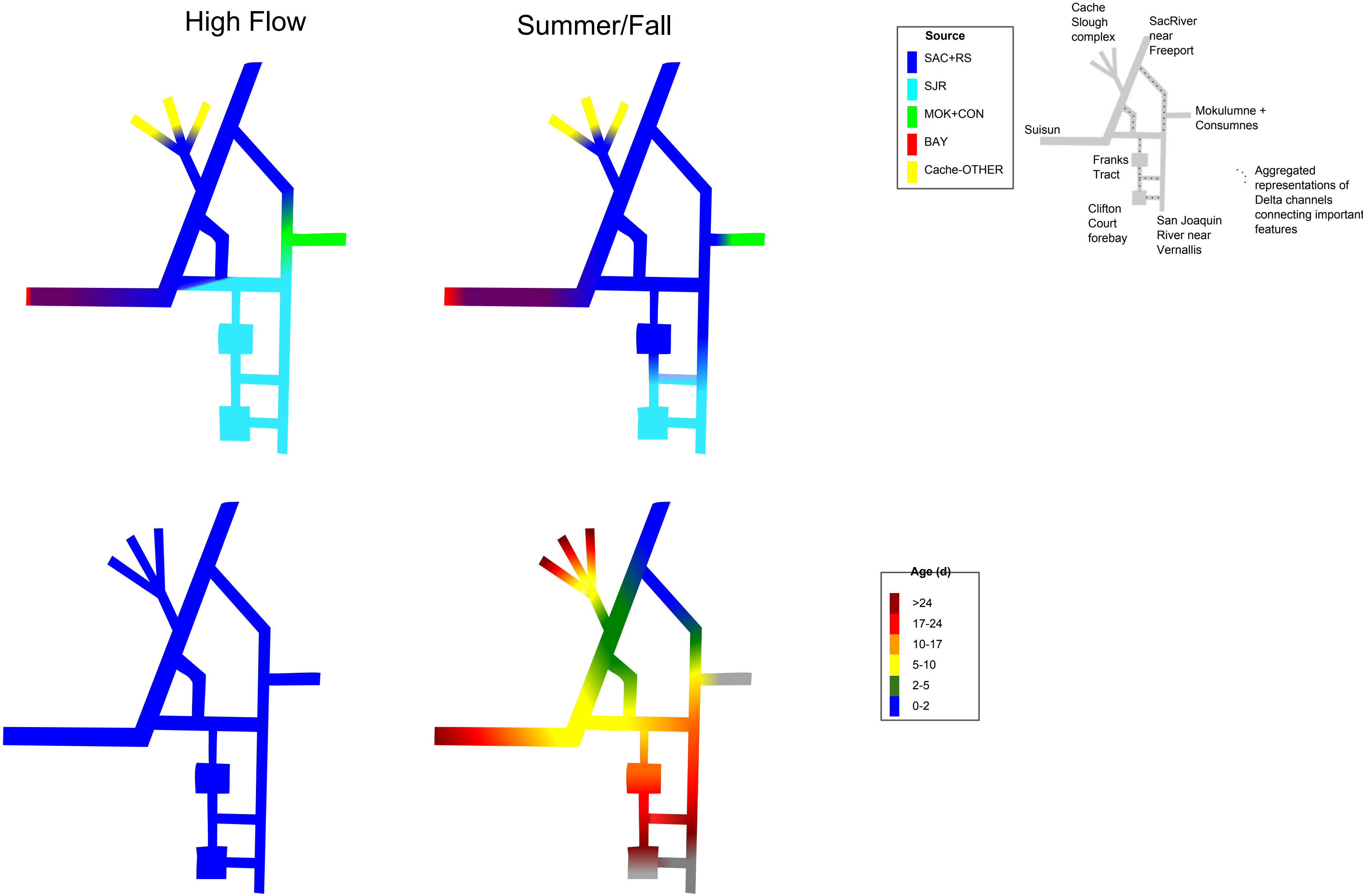


Figure Nuts.4. Idealized comparison of current and hypothesized-future concentrations along the Sacramento River main stem during winter/early-spring and summer. On the x-axis, zero represents discharge location. In terms of distance, the right-hand limit corresponds approximately to Chips Island, at the far east of Suisun Bay.


High Flow
Summer/Fall
Source
SAC+RS
SJR
MOK+CON
BAY
Cache-OTHER
Cache Slough complex
SacRiver near Freeport
Mokulumne + Consumnes
Suisun
Franks Tract
Clifton Court forebay
San Joaquin River near Vernallis
Aggregated representations of Delta channels connecting important features
Age (d)
>24
17-24
10-17
5-10
2-5
0-2

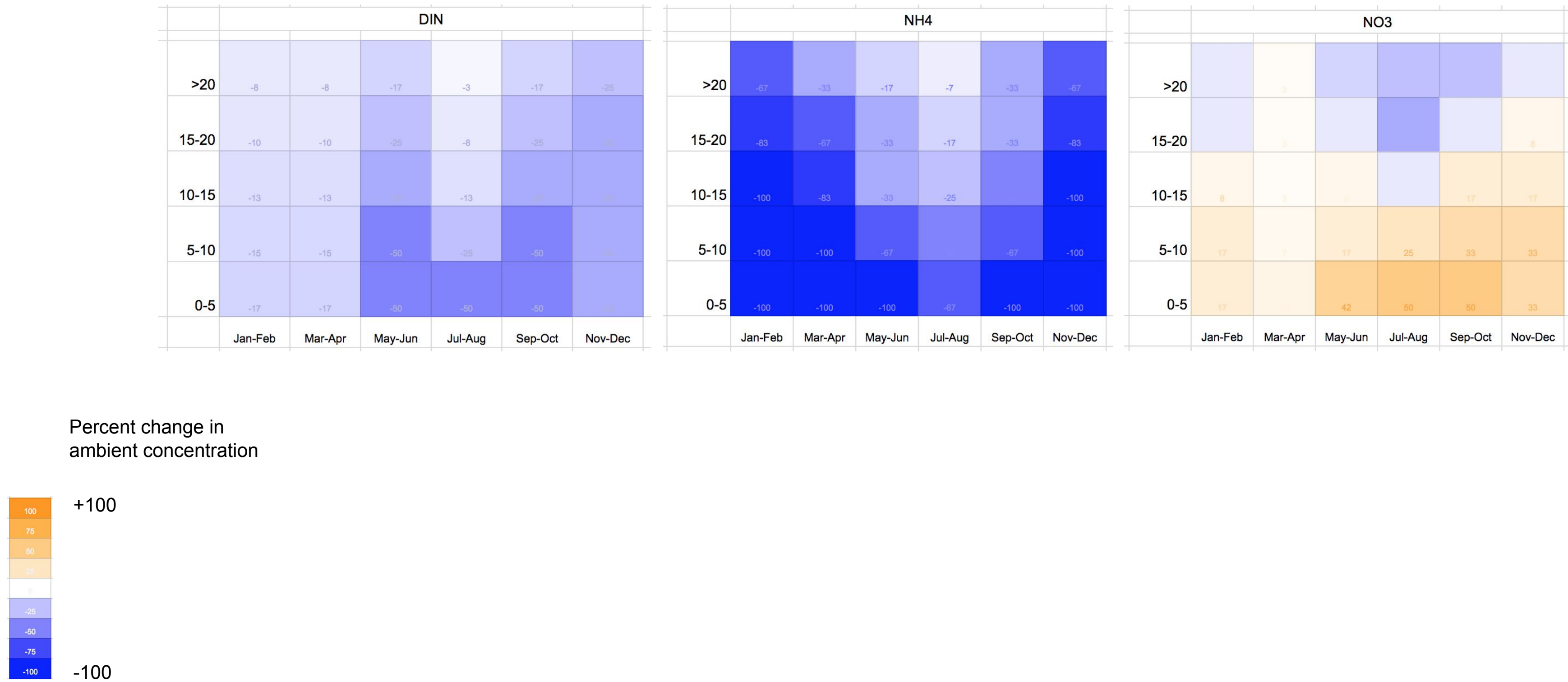


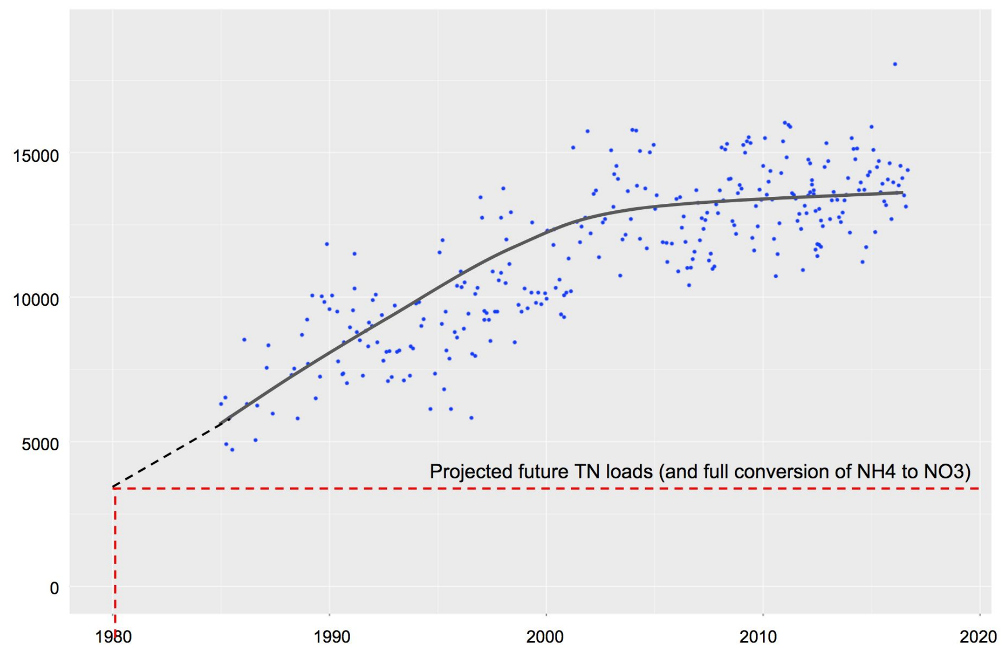
Figure Nuts.6 Semi-quantitative representation of relative changes in DIN, NH4, and NO3 concentrations as a function of the age of Sac River water containing effluent (time since discharge) and time of year.

Will nutrient concentrations return closer to ~1980 levels?

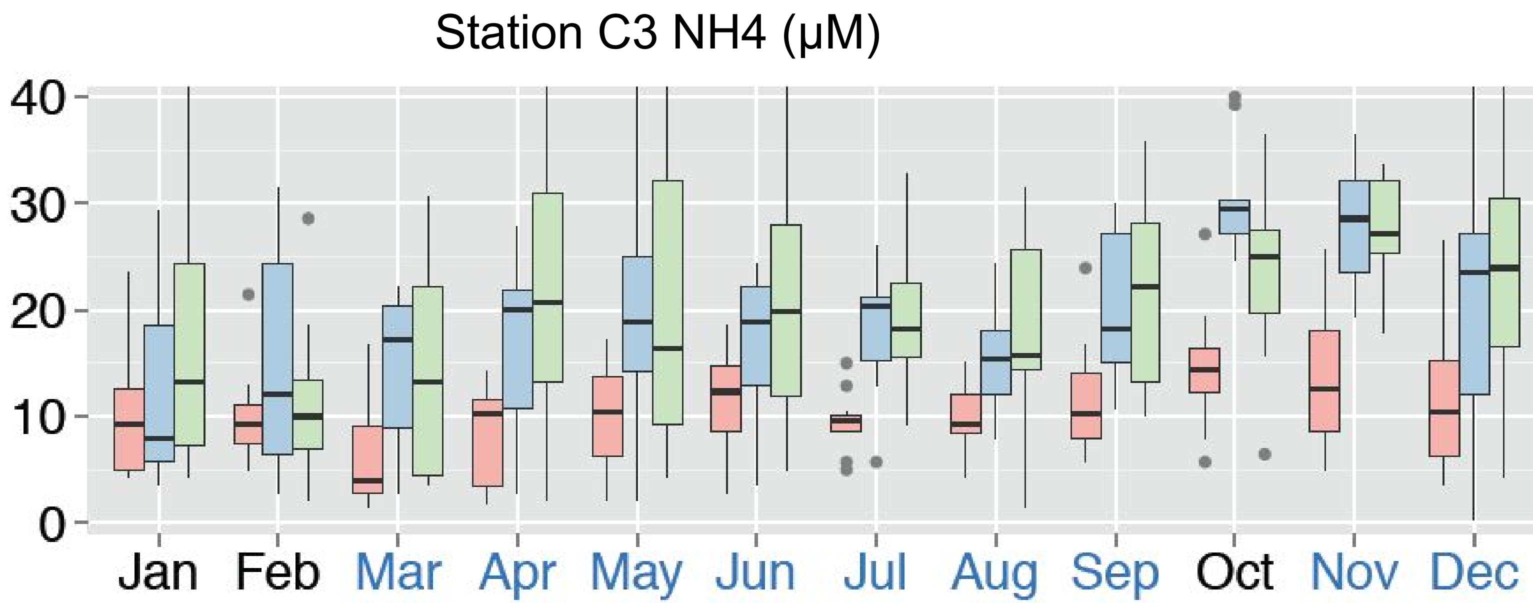
Many other factors and changes afoot...
ΔQ and Δflow-routing
Δlanduse
Δgrazers
ΔT
Δk_{att}
…

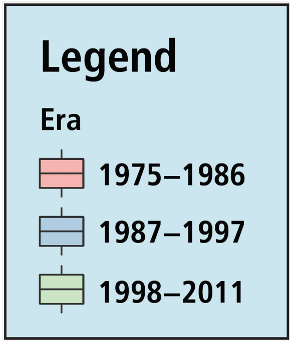
So, probably not. But past observations perhaps serve as an informative starting point for this current effort...

Regional San Monthly-averaged NH4 Loads (kg d^{-1})



How have late-spring/summer (May-Sep) ambient concentrations varied over time?





SFEI 2015

Data : DWR-EMP

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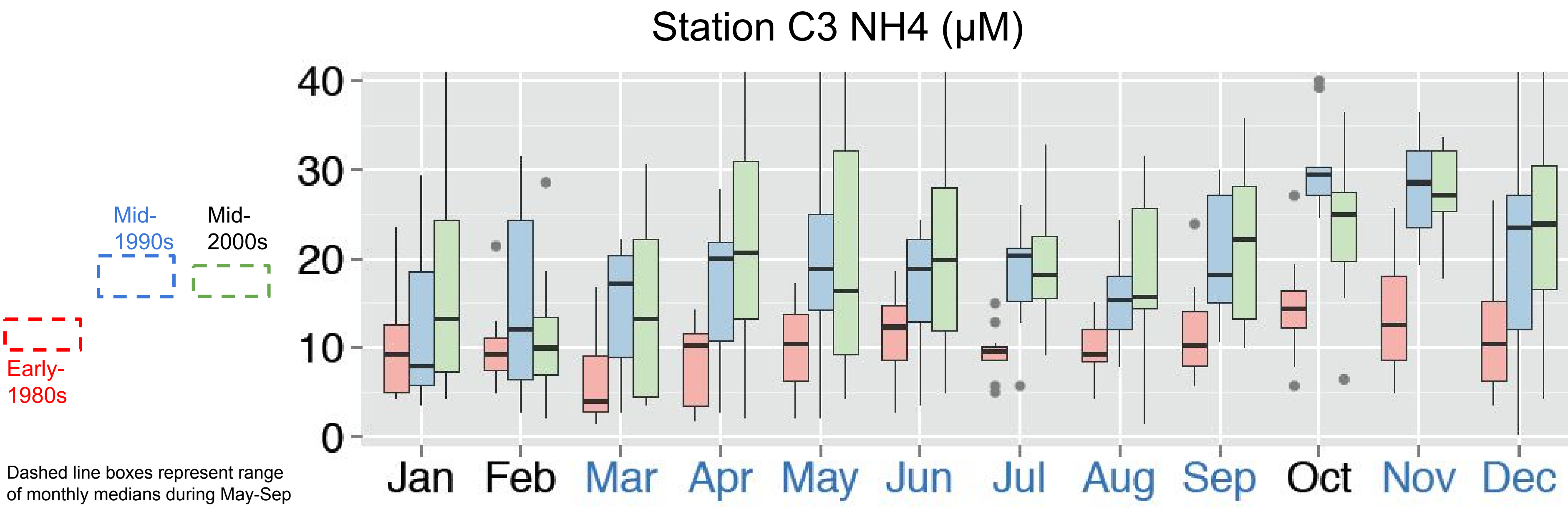
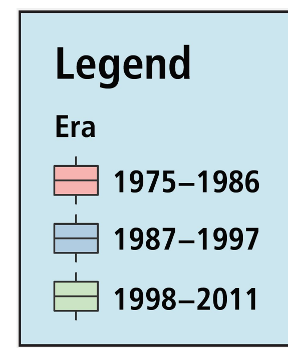


Dashed line boxes represent range of monthly medians during May-Sep

Median NH4 concentrations in 1990s-2000s were 1.5-2x those in early-1980s



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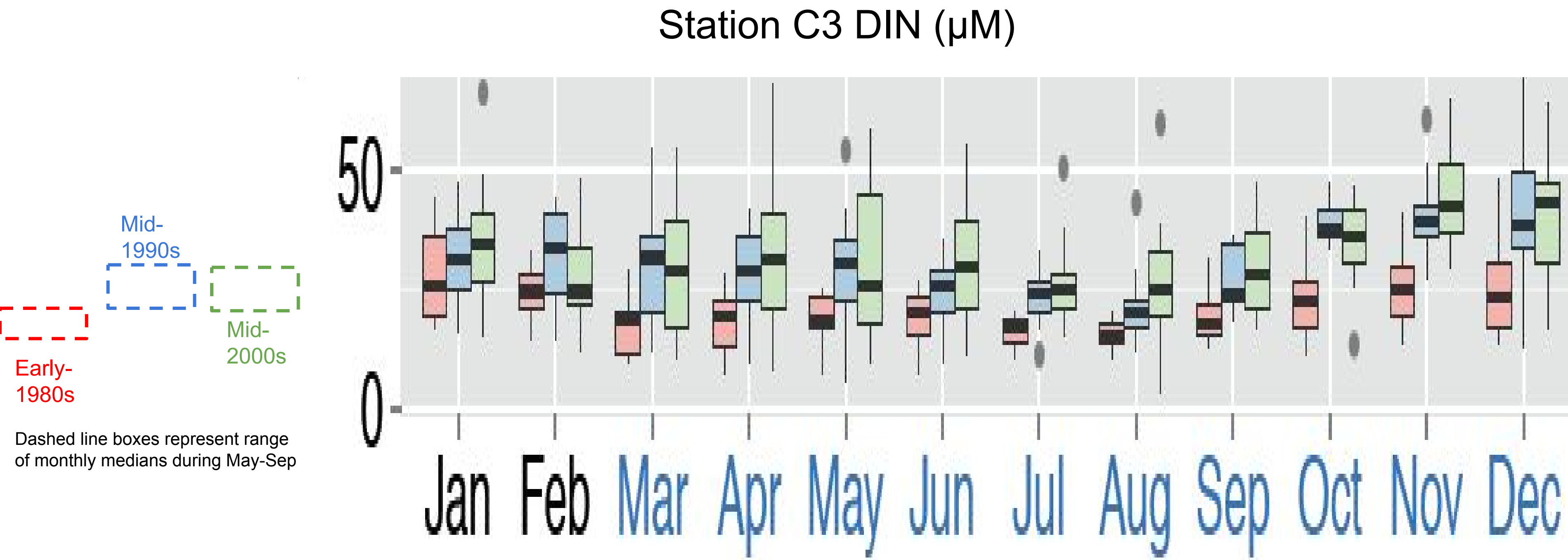

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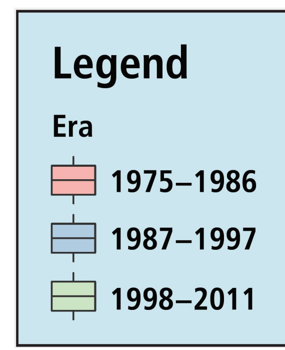
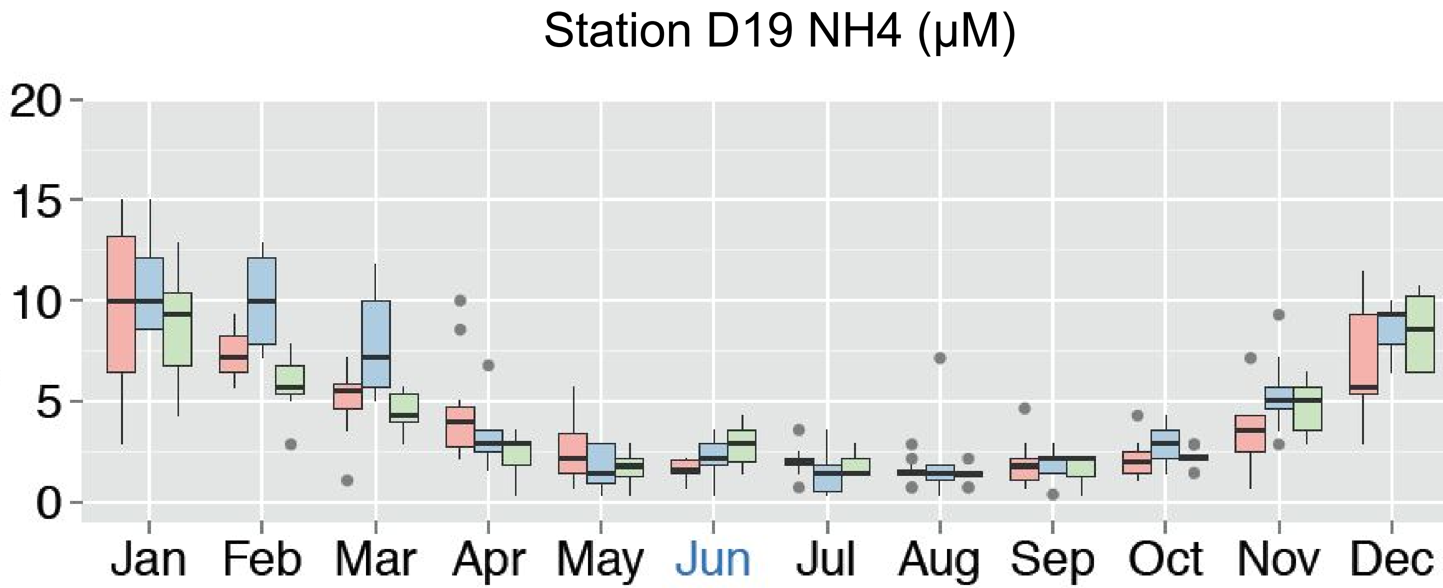


Median DIN concentrations in 1990s-2000s were 1.25-1.5x those in early-1980s.

SFEI 2015

Data : DWR-EMP

How have late-spring/summer (May-Sep) ambient concentrations varied over time?



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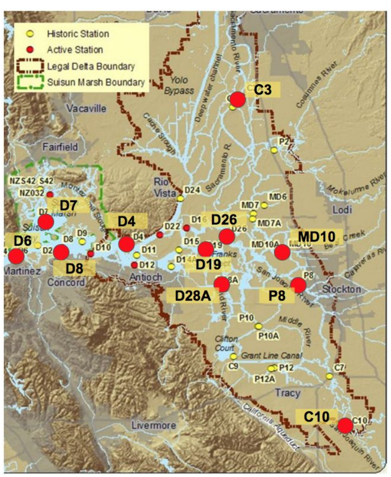
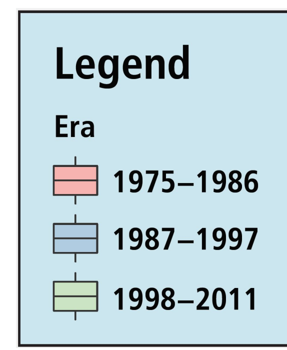


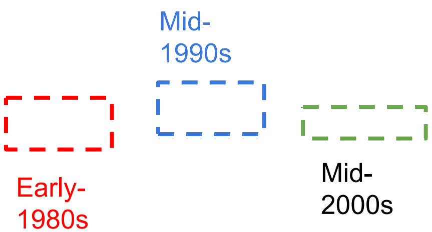


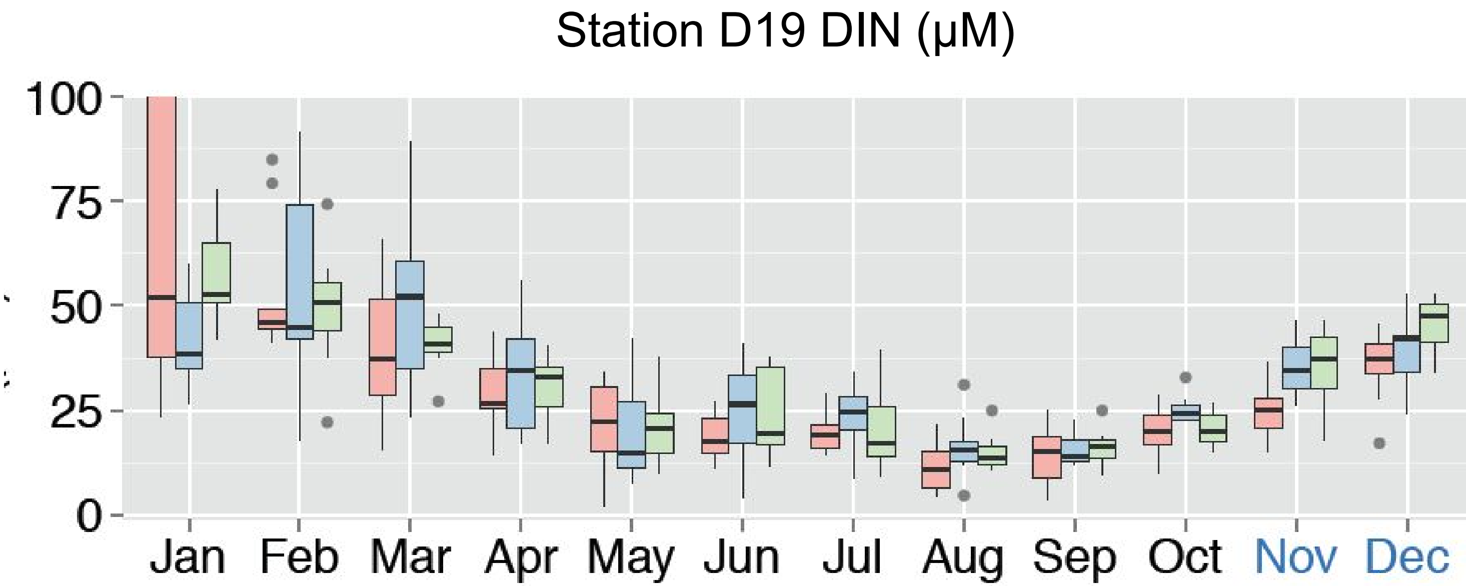
SFEI 2015

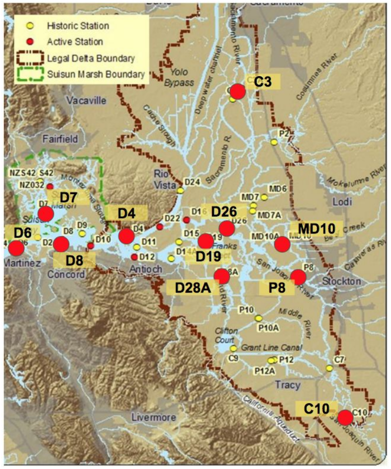
Data : DWR-EMP

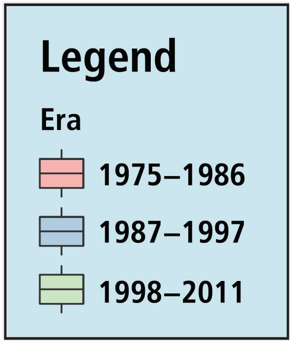
How have late-spring/summer (May-Sep) ambient concentrations varied over time?

Dashed line boxes to left and right represent range of monthly medians during May-Sep

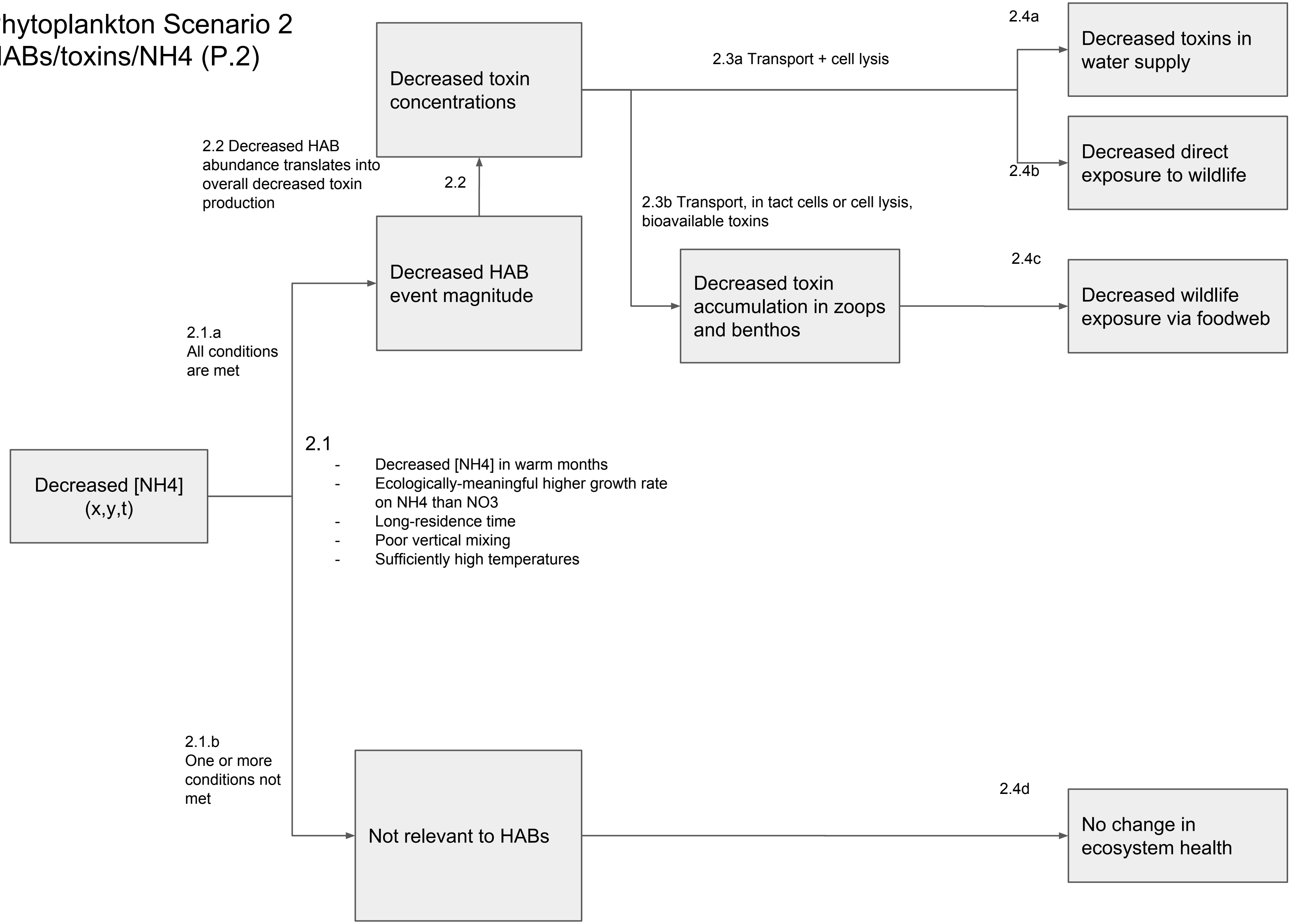


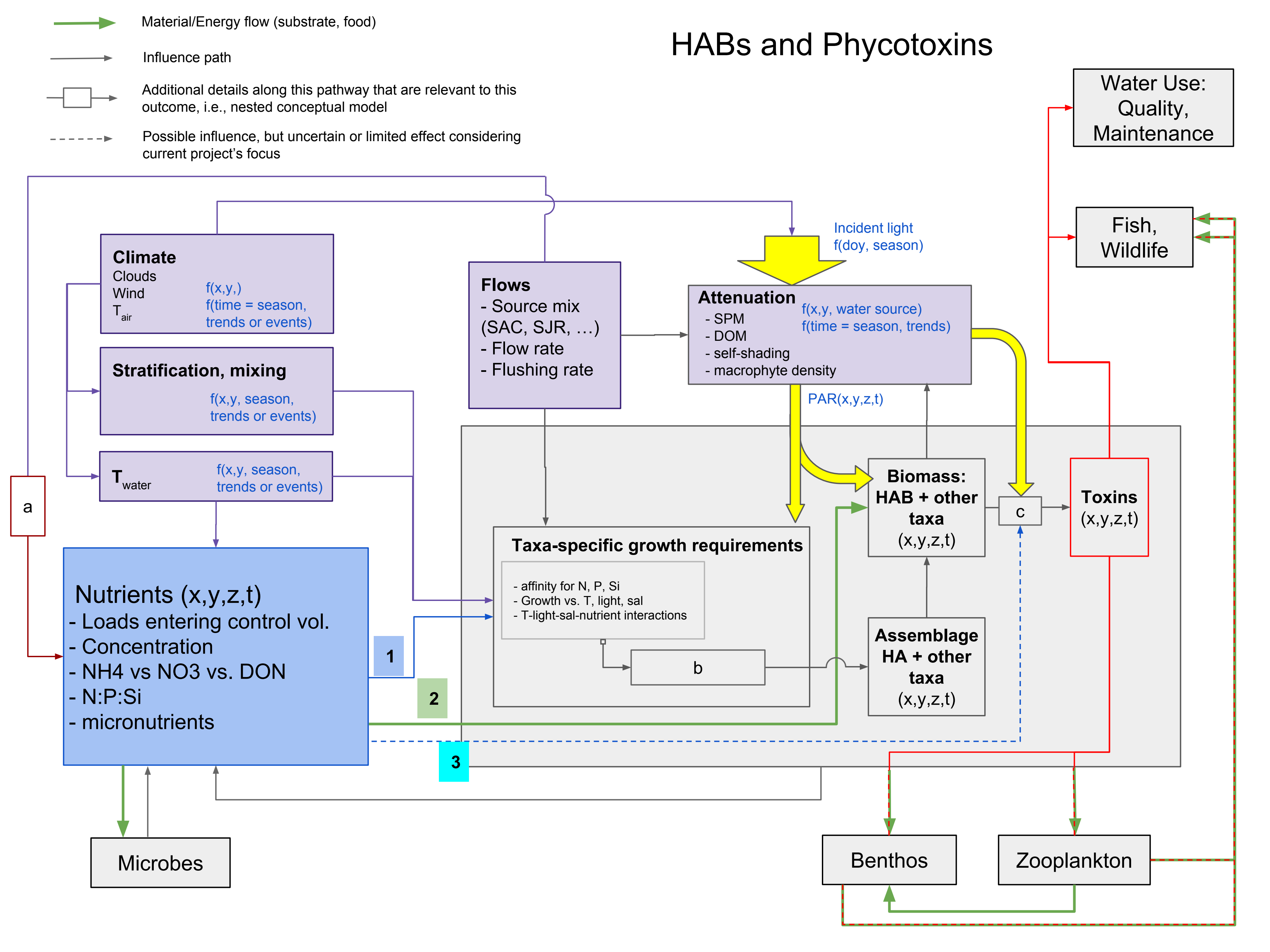




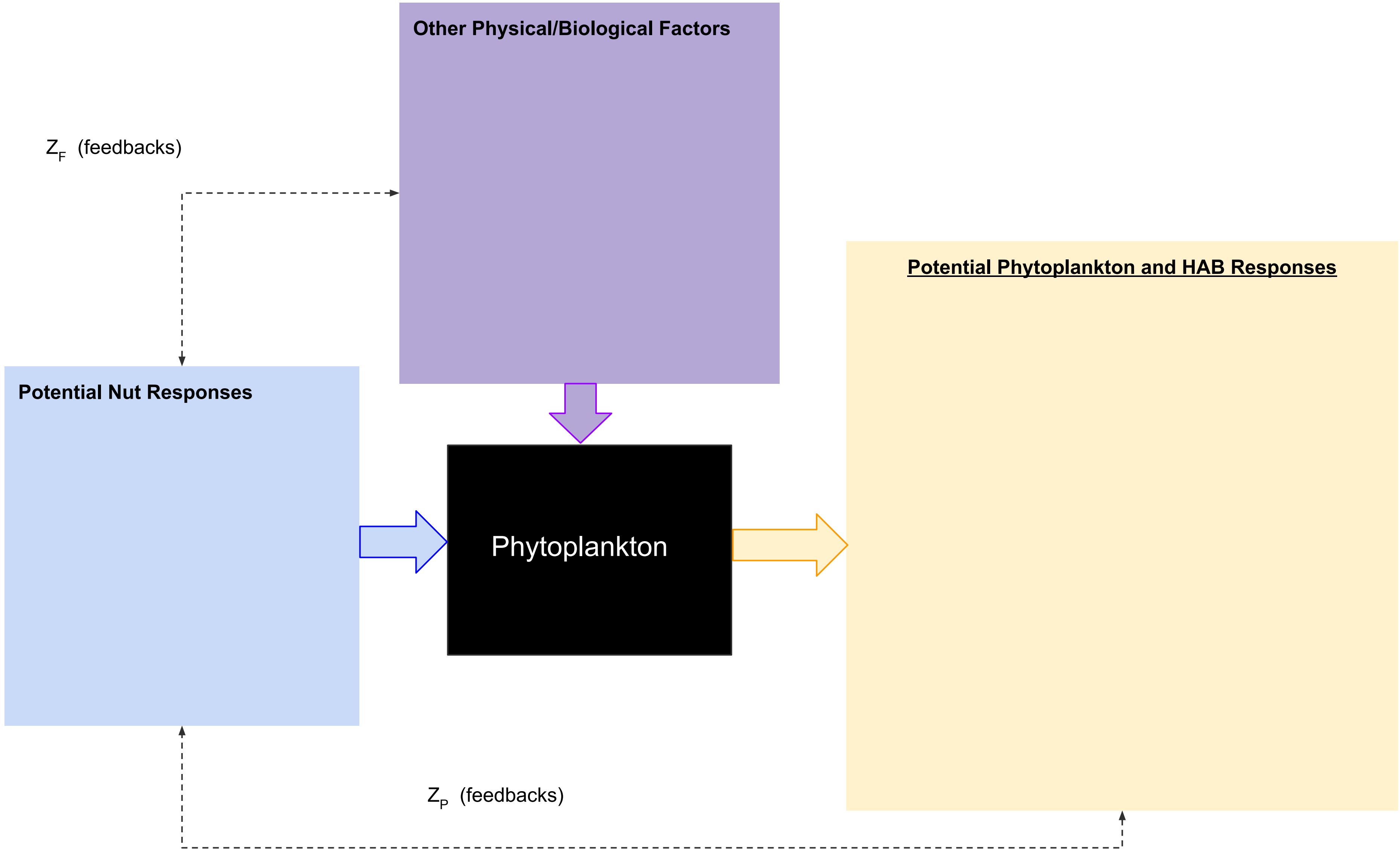


Phytoplankton Scenario 2
HABs/toxins/NH4 (P.2)

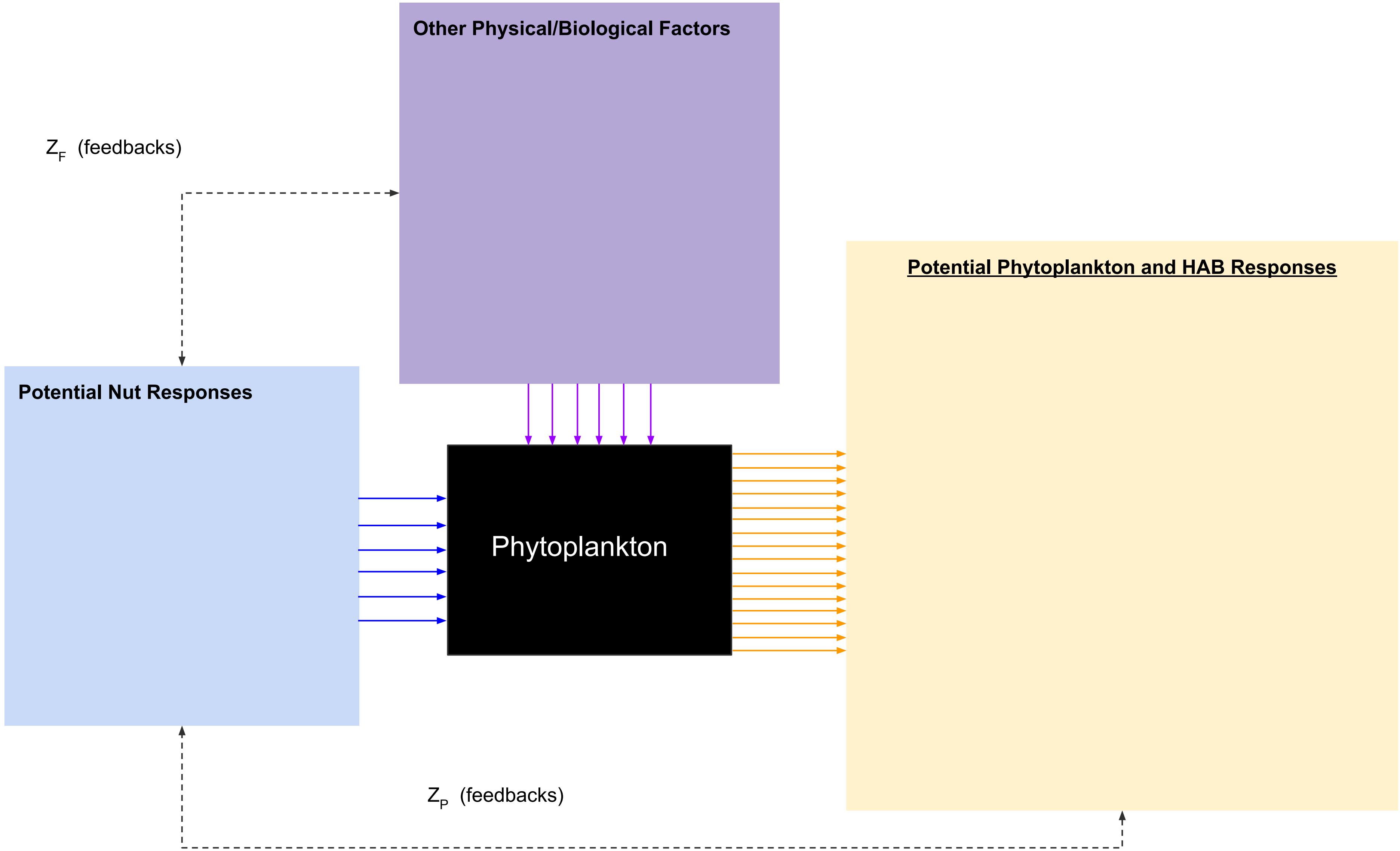


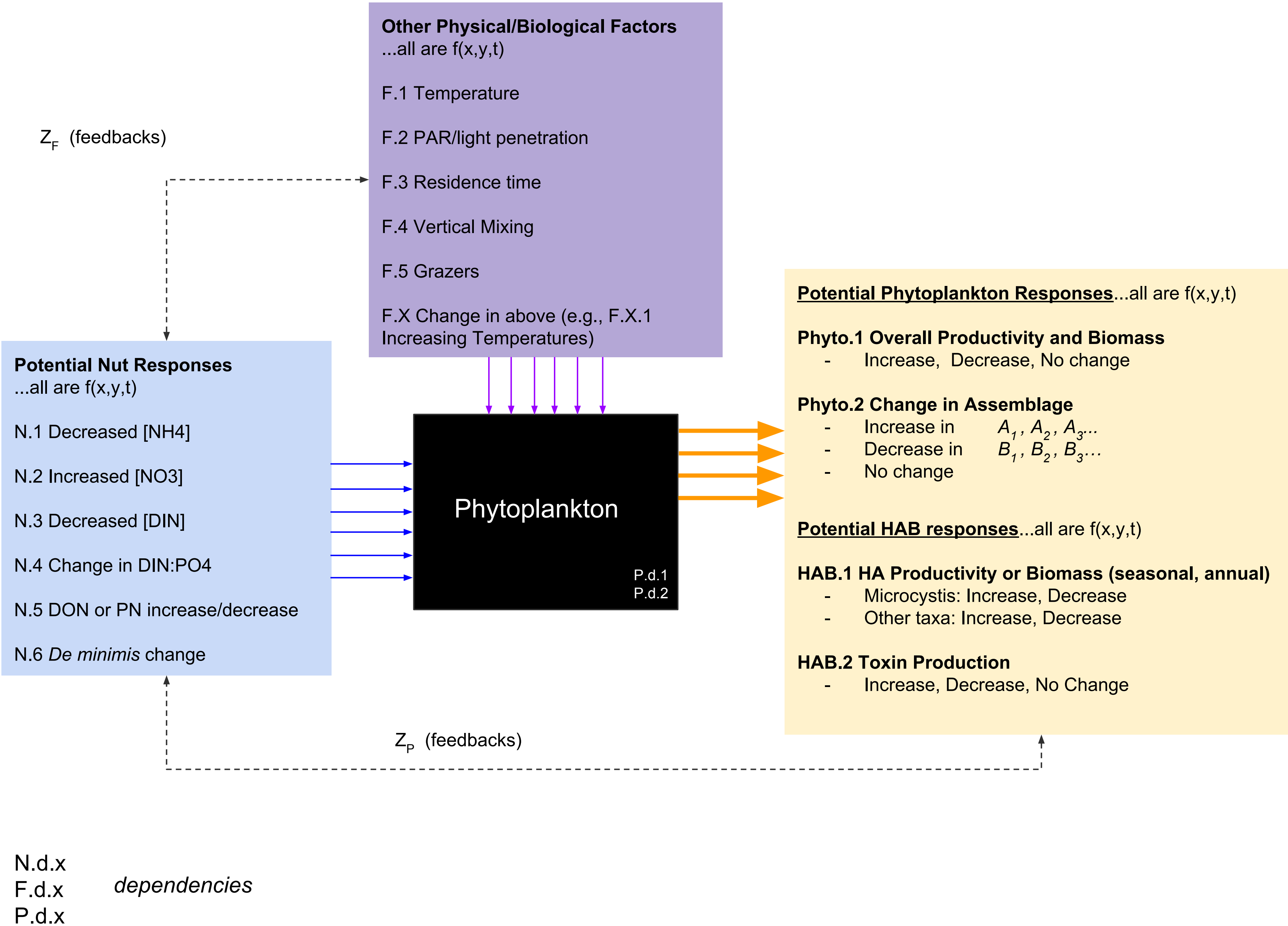


Material/Energy flow (substrate, food)
Influence path
Additional details along this pathway that are relevant to this outcome, i.e., nested conceptual model
Possible influence, but uncertain or limited effect considering current project's focus
HABs and Phycotoxins
Water Use: Quality, Maintenance
Fish, Wildlife
Incident light f(doy, season)
Climate
Clouds
Wind
T air
f(x,y,)
f(time = season, trends or events)
Flows
- Source mix (SAC, SJR, …)
- Flow rate
- Flushing rate
Attenuation
- SPM
- DOM
- self-shading
- macrophyte density
f(x,y, water source)
f(time = season, trends)
Stratification, mixing
f(x,y, season, trends or events)
PAR(x,y,z,t)
T water
f(x,y, season, trends or events)
a
Biomass: HAB + other taxa (x,y,z,t)
c
Toxins (x,y,z,t)
Taxa-specific growth requirements
- affinity for N, P, Si
- Growth vs. T, light, sal
- T-light-sal-nutrient interactions
b
Assemblage HA + other taxa (x,y,z,t)
Nutrients (x,y,z,t)
- Loads entering control vol.
- Concentration
- NH4 vs NO3 vs. DON
- N:P:Si
- micronutrients
1
2
3
Microbes
Benthos
Zooplankton

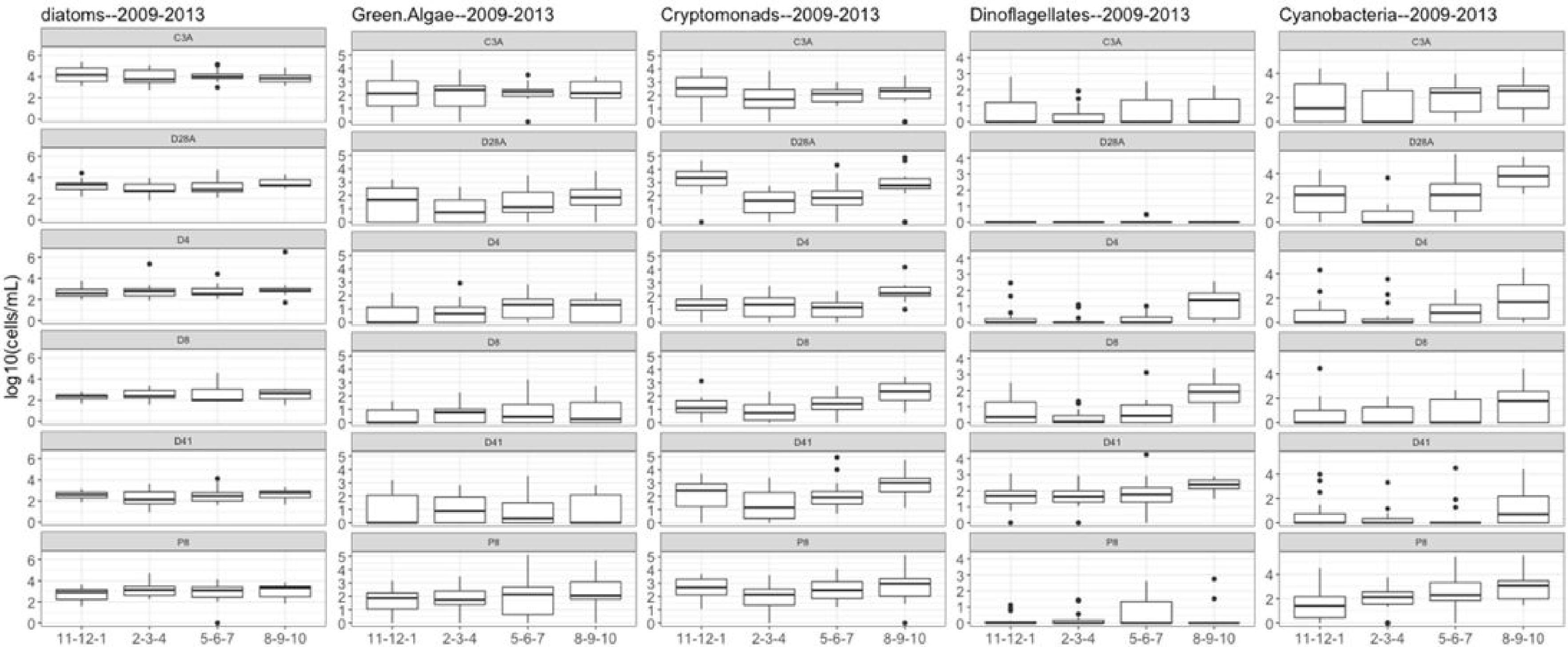


Other Physical/Biological Factors
Z_F (feedbacks)
Potential Phytoplankton and HAB Responses
Potential Nut Responses
Phytoplankton
Z_P (feedbacks)


Other Physical/Biological Factors
Z_F (feedbacks)
Potential Phytoplankton and HAB Responses
Potential Nut Responses
Phytoplankton
Z_P (feedbacks)



Other Physical/Biological Factors
...all are f(x,y,t)
F.1 Temperature
F.2 PAR/light penetration
F.3 Residence time
F.4 Vertical Mixing
F.5 Grazers
F.X Change in above (e.g., F.X.1 Increasing Temperatures)
Z_F (feedbacks)
Potential Nut Responses
...all are f(x,y,t)
N.1 Decreased [NH4]
N.2 Increased [NO3]
N.3 Decreased [DIN]
N.4 Change in DIN:PO4
N.5 DON or PN increase/decrease
N.6 *De minimis* change
Phytoplankton
P.d.1
P.d.2
Potential Phytoplankton Responses...all are f(x,y,t)
Phyto.1 Overall Productivity and Biomass
- Increase, Decrease, No change
Phyto.2 Change in Assemblage
- Increase in A_1, A_2, A_3...
- Decrease in B_1, B_2, B_3...
- No change
Potential HAB responses...all are f(x,y,t)
HAB.1 HA Productivity or Biomass (seasonal, annual)
- Microcystis: Increase, Decrease
- Other taxa: Increase, Decrease
HAB.2 Toxin Production
- Increase, Decrease, No Change
Z_P (feedbacks)
N.d.x
F.d.x
P.d.x
dependencies


diatoms--2009-2013
Green.Algae--2009-2013
Cryptomonads--2009-2013
Dinoflagellates--2009-2013
Cyanobacteria--2009-2013
C3A
D28A
D4
D8
D41
P8
log10(cells/mL)
11-12-1
2-3-4
5-6-7
8-9-10

Number of detections, relative frequency (in percent) from point samples, area (ha) and percent cover of the submersed aquatic plant species detected in the Sacramento-San Joaquin River Delta (waterways area is 639.89 ha)

Scientific name	Code	Status	Fall 2007			Summer 2008		
			Detections (%)	Area (ha)	% cover	Detections (%)	Area (ha)	% cover
Egeria densa	EGDE	Non-native	339 (89)	382.49	59.77	300 (69)	99.64	15.6
Cabomba caroliniana	CACA	Non-native	1 (0.3)	NA	NA	36 (8)	1.41	0.2
Myriophyllum spicatum	MYSP	Non-native	32 (8)	68.03	10.6	78 (18)	20.4	3.2
Potamogeton crispus	POCR	Non-native	52 (14)	50.8	7.9	53 (12)	10.03	1.6
Total			424	382.9	59.8	467	174.08	27.2
Ceratophyllum demersum	CEDE	Native	107 (28)	283.77	44.3	180 (41)	59.14	9.2
Potamogeton nodosus	PONO	Native	1 (0.3)	NA	NA	10 (2)	6.04	0.9
Elodea canadensis	ELCA	Native	19 (5)	34.28	5.36	10 (2)	18.29	2.9
Stuckenia spp.	STSPP	Native	24 (6)	73.02	11.4	32 (7)	69.84	10.9
Total			151	294.29	45.9	232	157.04	24.5
Total submersed species			575	388.35	60.7	699	239.6	37.4

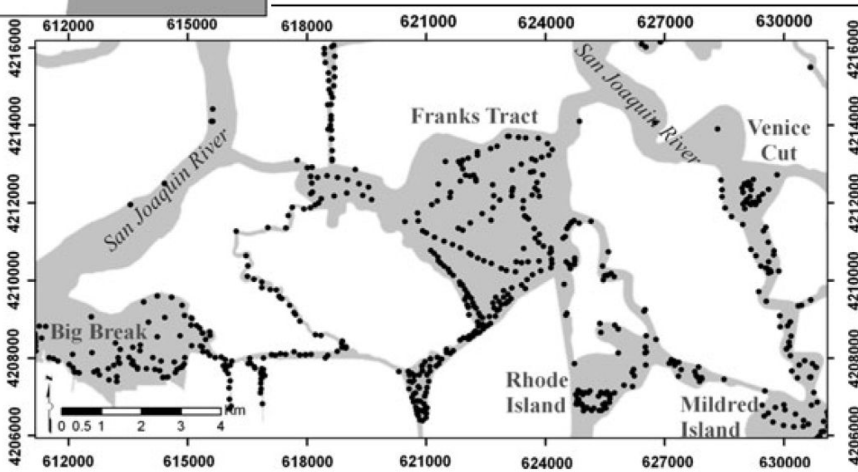
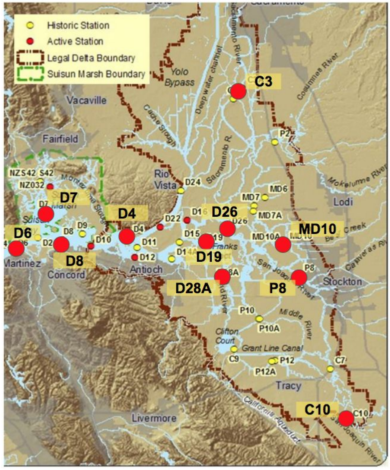


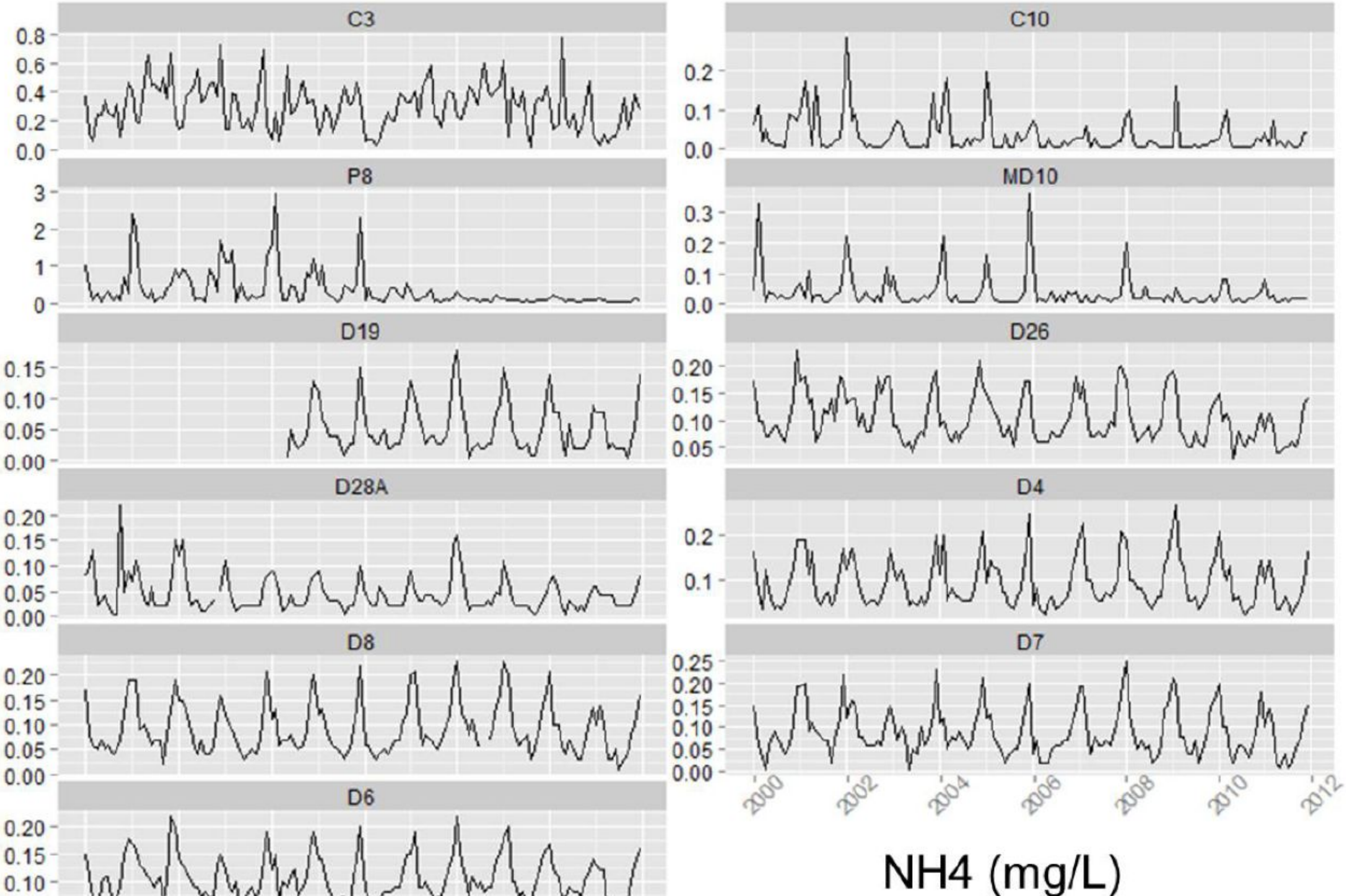
Figure. 2.1. Rake detections and other data (above) on abundance of submersed species at sampling points within the central Delta (left). Excerpted from Santos et al. 2011.

Figure 2.3. Species central to this review. Left, submersed species: *Egeria densa* (top; photo Katharyn Boyer), *Ceratophyllum demersum* (middle, photo Ron Vanderhoff), and *Stuckenia pectinata* (bottom; photo Katharyn Boyer). Right, floating species: *Eichhornia crassipes* (top; photo Bob Case), *Ludwigia* spp. (center; photo alabamaplants.com), *Hydrocotyle umbellata* (bottom; photo southeasternflora.com).

Substantial seasonal and interannual variability…

Predictable?





SFEI 2015

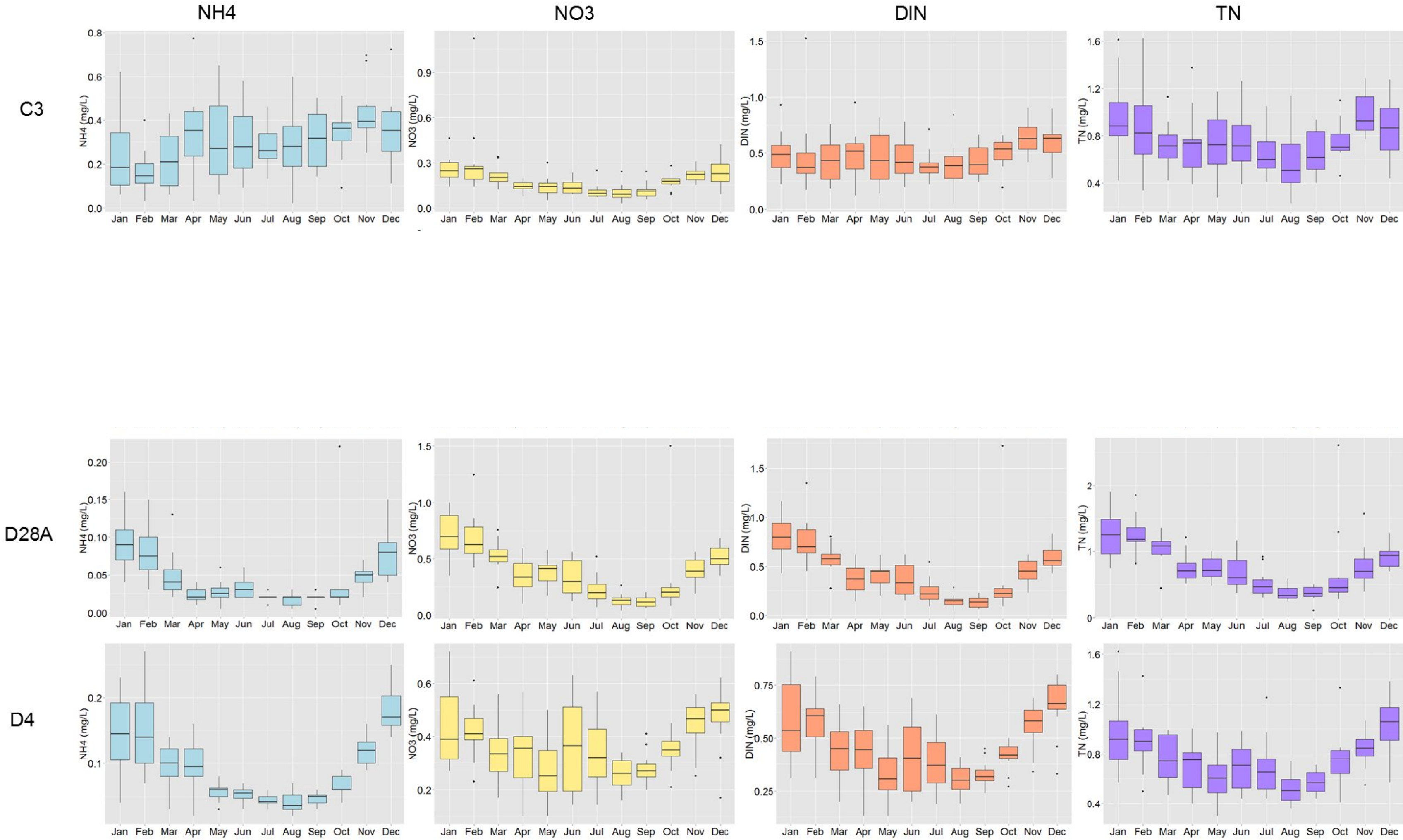
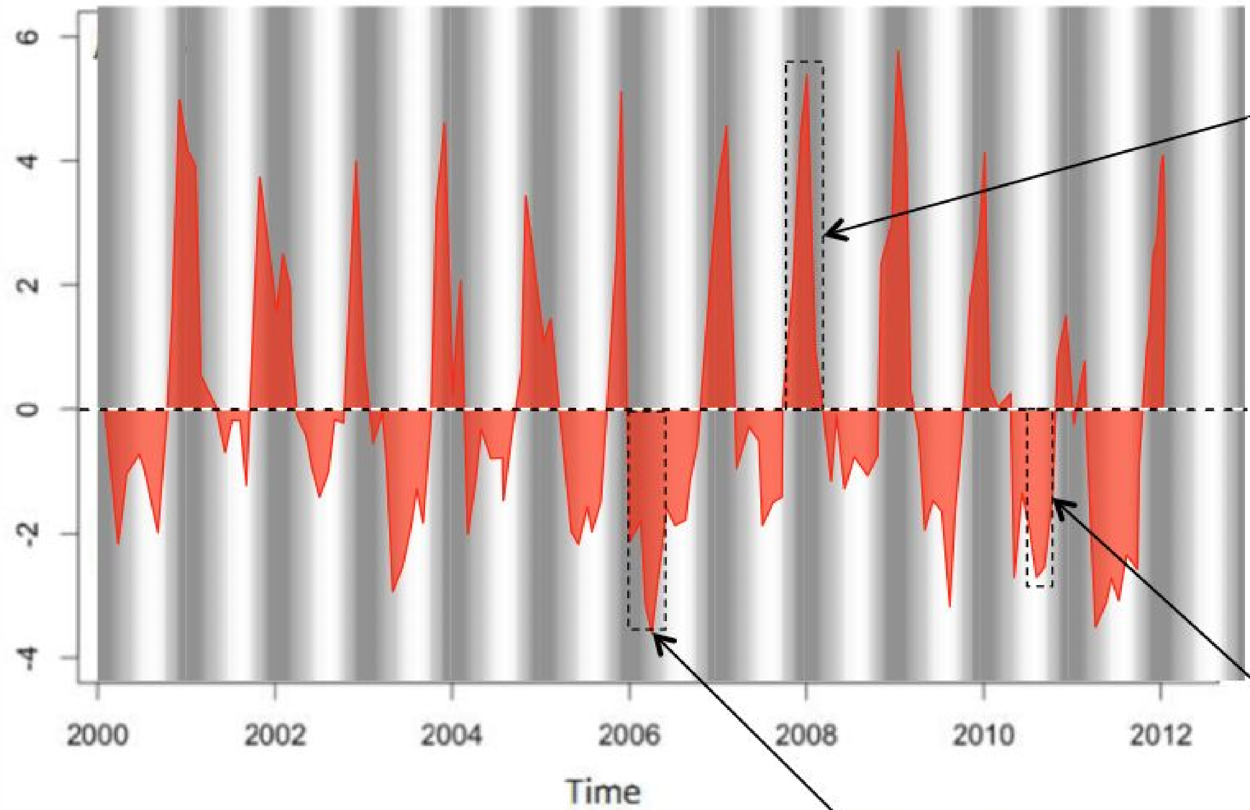


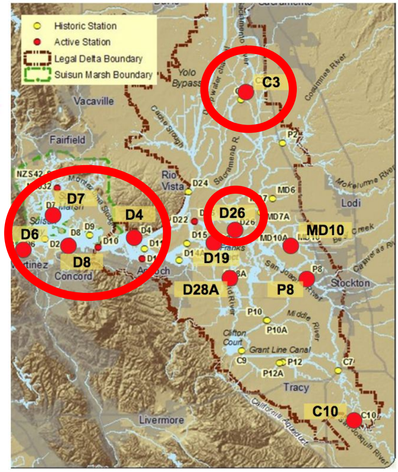
Figure 11 Boxplots on NH4, NO3, DIN and TN concentrations at a subset of DWR-IEP stations for the period 2000-2011. The boxes show median concentration and 25th/75th percentiles, and the whiskers extend to 1.5x the interquartile range. Anything beyond that are considered outliers and shown with dots. Note the varying y-axis scales.

Example seasonal cycles, need to select some better stations

Dominant ‘modes’ of seasonal variations in NH4 concentration



Increase and peak during cool/cold weather
- Low nitrification
- Low uptake by algae



Summer decrease
- Nitrification
- Uptake by algae

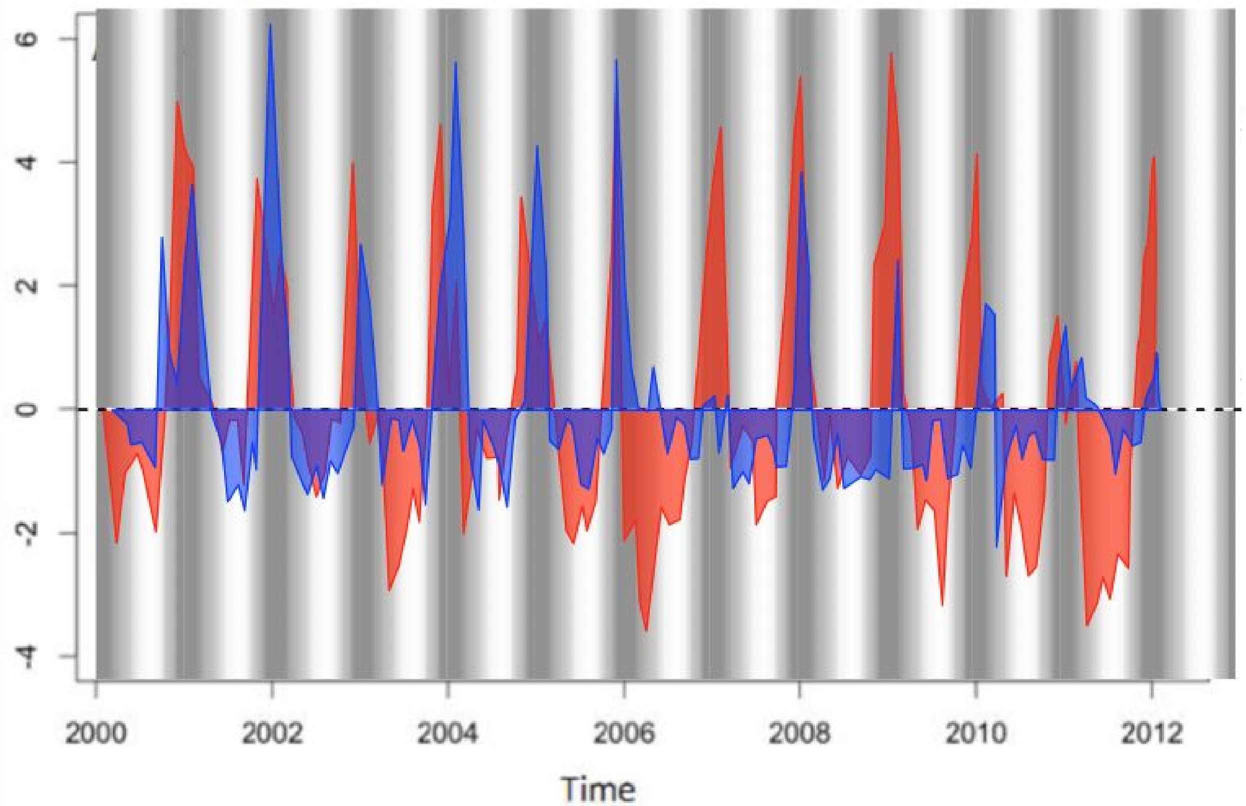
March-May decrease,
- higher flows
- dilution

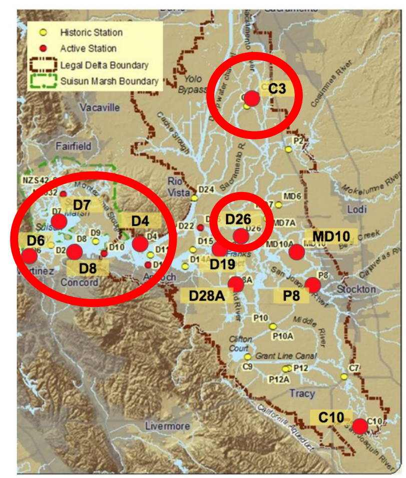
EOF1 =	D8, D7, D6, D4	(strong)
	D26	(strong)
	C3	(moderate)

EOF = Empirical orthogonal functions

2 EOFs explained 73% of variance

Dominant 'modes' of seasonal variations in NH4 concentration





EOF1 =	D8, D7, D6, D4	(strong)
	D26	(strong)
	C3	(moderate)

EOF2 =	P8, MD10, C10	(strong)
	D28	(moderate)
	-C3	(strong)

EOF = Empirical orthogonal functions

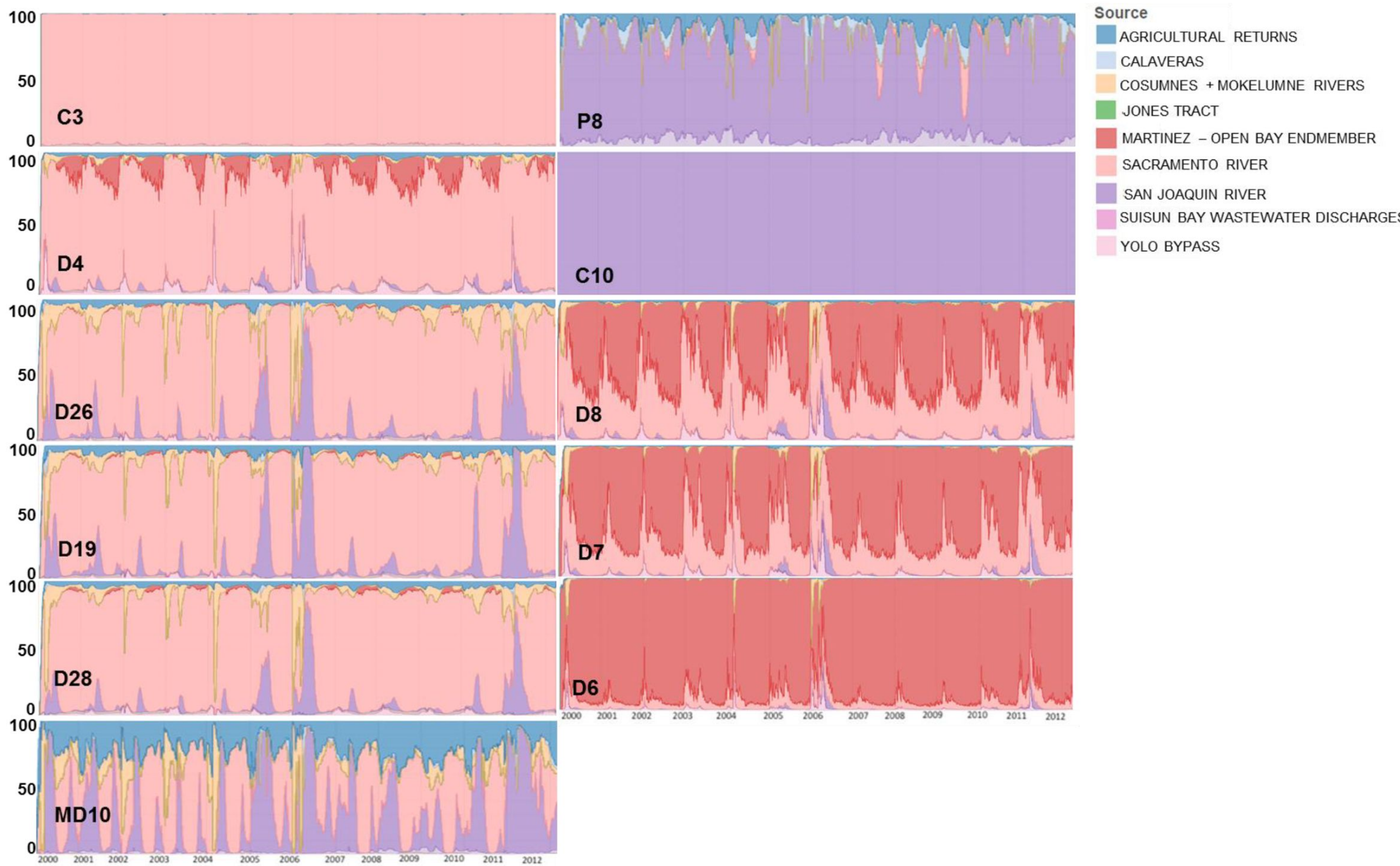


Figure 10 Percent contribution of each end member to water volume at DWR-IEP water quality stations. Data: DSM2 Model output

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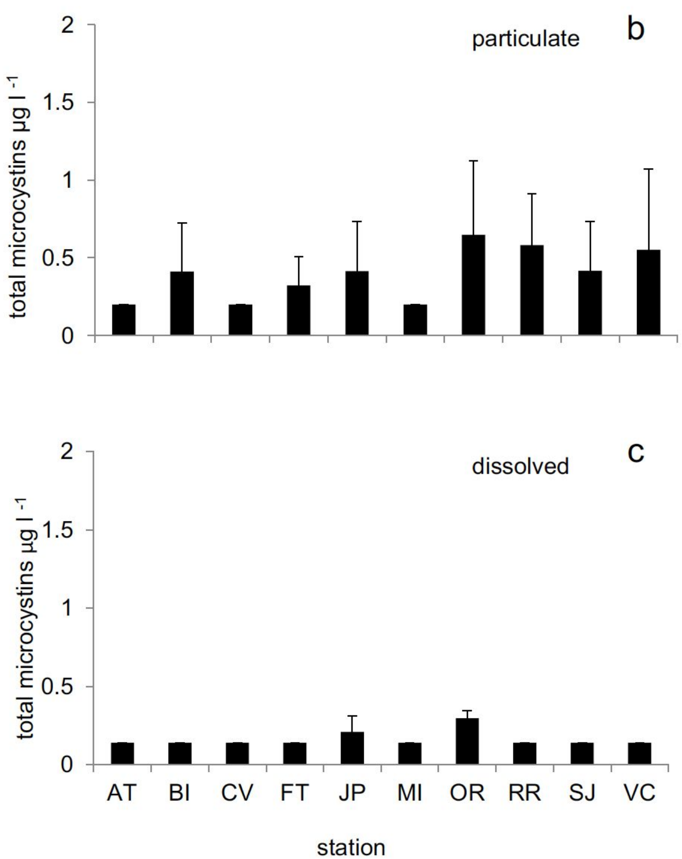
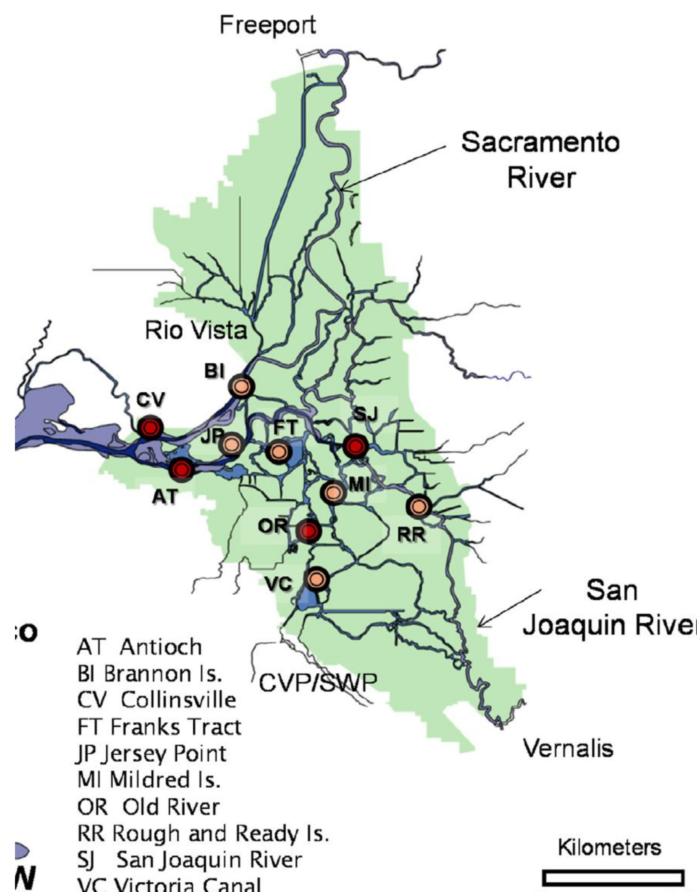
Impacts of the 2014 severe drought on the *Microcystis* bloom in San Francisco Estuary

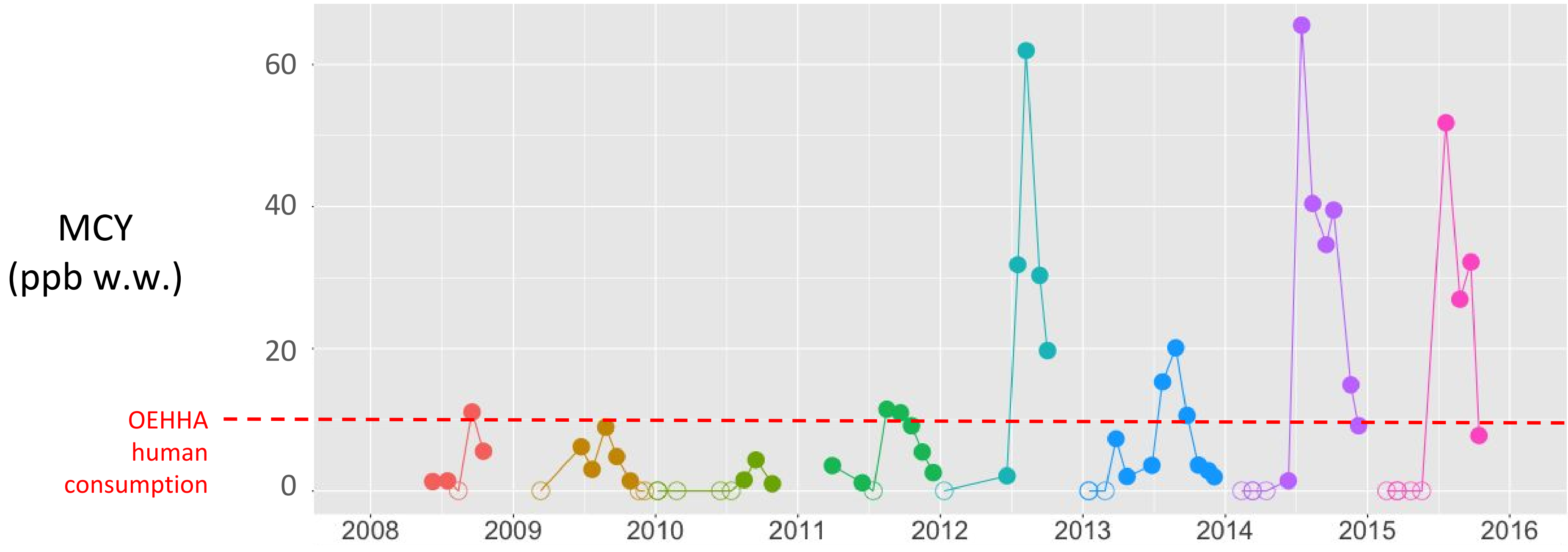
P.W. Lehman[a,*], T. Kurobe[b], S. Lesmeister[c], D. Baxa[b], A. Tung[c], S.J. Teh[b]

"The 2014 Microcystis bloom had the highest biomass and toxin concentration, earliest initiation, and the longest duration, since the blooms began in 1999. "





Toxin Sources: Microystin in monthly archived *Potamocorbula Amurensis*



SFEI 2016 (collaboration with T Otten and R Stewart

- Commonly exceeded OEHHA action level for human consumption (10 ppb)
- No state standards for protecting biota
- MCY exceeds concentrations that have yielded subacute affects in secondary consumers (OEHHA, 2009)

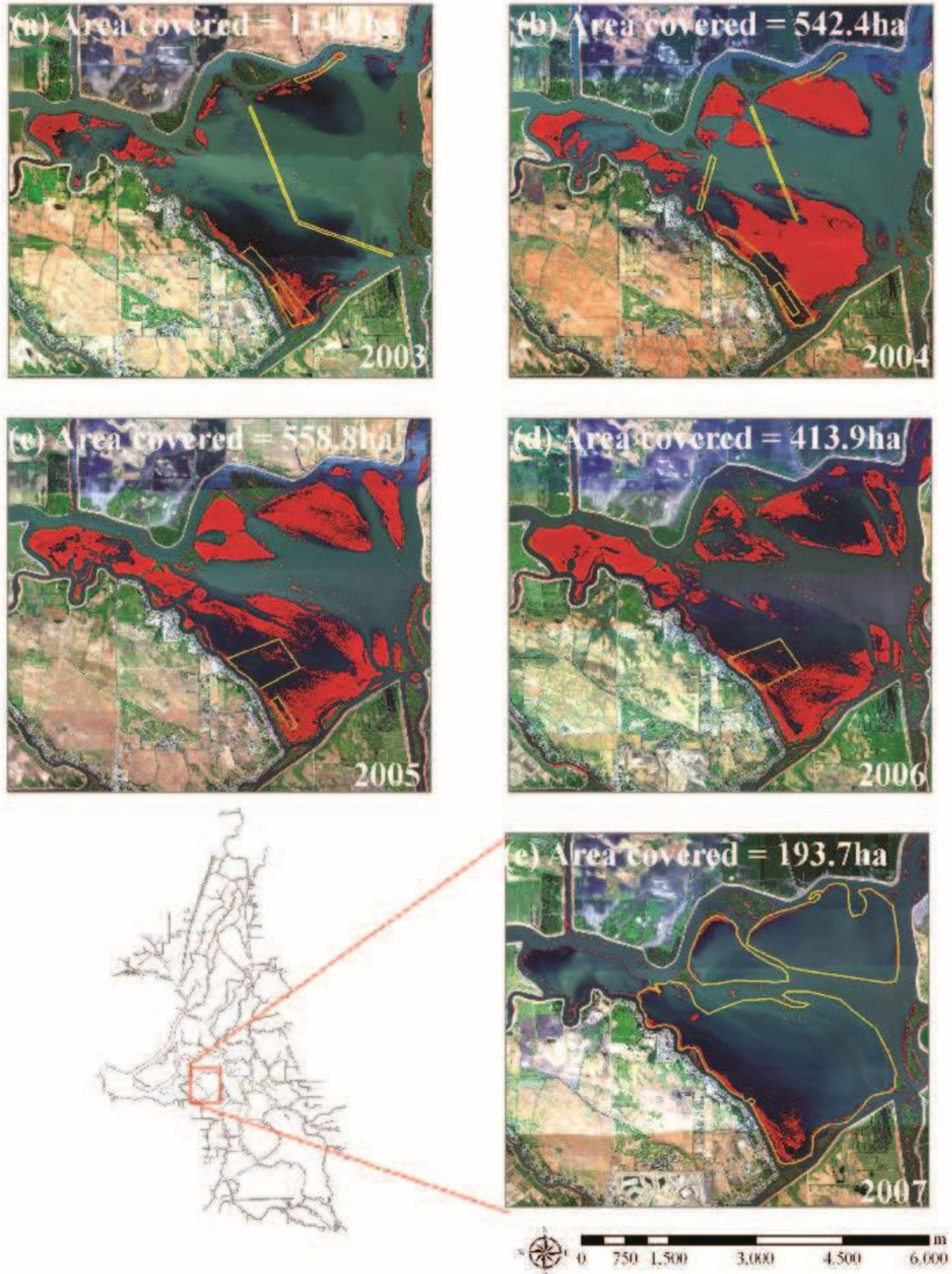


Figure 2.4. Submersed vegetation (primarily *E. densa*) coverage of up to 560 hectares within Franks Tract in the central Delta, 2003-2007 (Figure from Santos et al. 2009).